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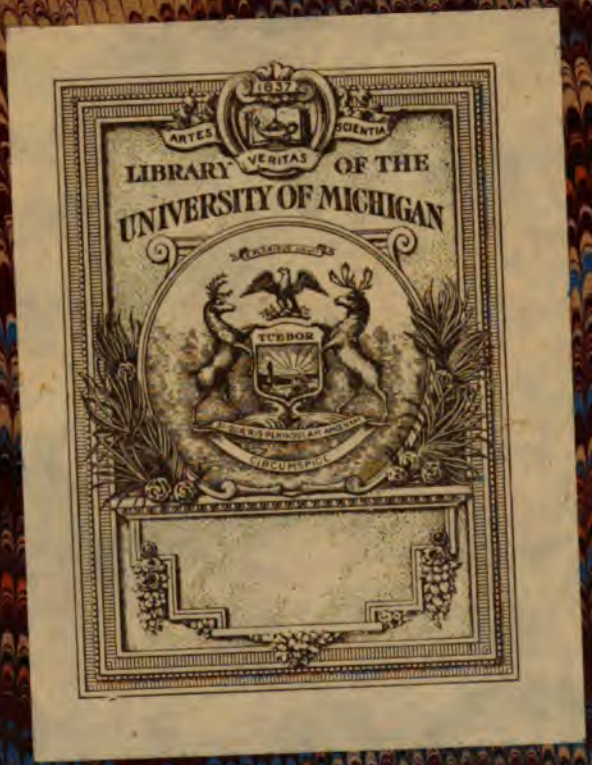
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THE

ROTHAMSTED MEMOIRS

ON

AGRICULTURAL CHEMISTRY

AND

PHYSIOLOGY.

BY

SIR JOHN BENNET LAWES, BART., D.C.L., SC.D., LL.D., F.R.S., &c.

OF ROTHAMSTED, HERTS,

AND

SIR J. HENRY GILBERT, M.A., SC.D., LL.D., F.R.S., V.P.C.S., &c.

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EXPERIMENTS ON VEGETATION,

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RESULTS OF EXPERIMENTS AT ROTHAMSTED,

ON THE

QUESTION OF THE

FIXATION OF FREE NITROGEN;

BEING

(WITH ADDITIONS)

A LECTURE DELIVERED JULY 18, 1890,

AT THE

ROYAL AGRICULTURAL COLLEGE,

CIRENCESTER,

BY

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HONORARY PROFESSOR OF THE COLLEGE.

FROM THE "AGRICULTURAL STUDENTS' GAZETTE."
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RESULTS OF EXPERIMENTS AT ROTHAMSTED, ON THE QUESTION OF THE FIXATION OF FREE NITROGEN.

INTRODUCTION.

A large portion of the lecture on the conditions and results of growth of Leguminous Crops, which I gave at the College last year, was devoted to the illustration of the fact, that both the scientific interest, and the practical value, of those crops, depended very much on the amount of nitrogen which they contain, and on the sources of their nitrogen; and especially on the great differences in these respects, between them and the representatives of the other families with which they are grown, either in alternation in our rotations, or in association in our meadows and pastures. I then discussed the bearing of existing evidence on the question of the fixation of free nitrogen, and concluded by reference to some considerations and illustrations relating to the question of the sources of the nitrogen of crops generally.

With regard to the question of the fixation of free nitrogen, I stated—that nearly a century ago it was a matter of discussion whether plants took up, or evolved, free nitrogen; that it was just about half a century since Boussingault commenced experiments to determine whether plants did assimilate free nitrogen; that from his results he concluded that they did not; that results obtained at Rothamsted, about 30 years ago, confirmed those of Boussingault; but that others had come to an opposite conclusion.

During the last few years, however, the discussion has assumed a somewhat different aspect. The question still is whether the free nitrogen of the air is an important source of the nitrogen of vegetation; but whilst few now assume that chlorophyllous plants directly assimilate free nitrogen, it is nevertheless supposed to be brought under contribution in various ways; coming into combination—by the agency of electricity, within the soil, or within the plant; or under the influence of micro-organisms, or of other low forms, either within the soil itself, or in symbiotic growth with a higher plant.

The recent experiments, results, and conclusions, of Berthelot, Dehérain, Joulie, Dietzell, Frank, Hellriegel and Wilfarth, Emil von Wolff, and Atwater, were considered; as also were the later experiments of Boussingault in their bearing on an aspect of the question which has since come into prominence, namely, that of the fixation of free nitrogen within the soil under the influence of lower organisms.*

* For a fuller account of the results of Berthelot, and others, above referred to, and for references to their papers, see our paper in the "Philosophical Transactions," Vol. 180. B.

It was concluded that, of all the recent results bearing upon the subject, those of Hellriegel and Wilfarth, with certain leguminous plants, were by far the most definite and significant; and I stated that it had, accordingly, been decided to make experiments at Rothamsted on somewhat similar lines. I further stated, that a preliminary series had been undertaken in 1888, and a more extended one in 1889, and I exhibited photographs of some of the experimentally grown plants. Some of the numerical results have since been published, and they show a considerable fixation of free nitrogen. Much, however, still remains to be done; and many points necessary for drawing conclusions as to the practical importance of such fixation are as yet unsettled. The subject is, in fact, being further investigated at Rothamsted in the present year, 1890. I have, nevertheless, thought that enough was so far established, to supply material of sufficient interest for the subject of my present lecture: and, accordingly, I propose to bring before you to-day—*Results of Experiments at Rothamsted on the Question of the Fixation of Free Nitrogen.*

Before, however, describing the conditions and the results of the recent experiments, which do show a fixation of free nitrogen, it will be well to call attention to those of the earlier experiments, which did not indicate any fixation; as the well-defined difference in the conditions under which such different results were obtained, will bring clearly to view what are the conditions under which fixation does, and what are those under which it does not, take place. We shall thus, too, be the better able to form some judgment as to the practical bearing of the recent results.

THE EARLIER EXPERIMENTS, WHICH DID NOT SHOW FIXATION OF FREE NITROGEN.

I have already stated that the results and conclusions of Boussingault were against the supposition that plants assimilate the free nitrogen of the atmosphere. His numerous experiments on the subject were commenced in 1837, and were continued at intervals up to 1858. His soils consisted of burnt soil, washed and ignited pumice, or burnt brick; his experiments were sometimes in free air, in a summer house, sometimes in a closed vessel with limited air, sometimes with a current of washed air, and sometimes in free air, but under a glass case. When the plants were enclosed, a supply of carbonic acid was provided, and in a few cases known quantities of nitre were supplied as manure. In all, distilled water was used for watering. Thus, in all cases the substances he used as soil were sterilised; in some the supplied air was washed; whilst in others the plants grew in limited air, or were more or less protected. He experimented with a great variety of plants—wheat, and oats, representing Gramineæ; clover, peas, haricots, and lupins, as Leguminosæ; also garden cress and sunflower.

In some of his earlier experiments, conducted in free air in a summer house, the Leguminous plants, trefoil and peas, did indicate

some gain of nitrogen; but in all his subsequent experiments there was generally either a slight loss, or, if a gain, it was represented by only fractions, or low units of milligrams; the larger amounts being with Leguminosæ, in free air, under a glazed case. After 20 years of varied and laborious investigation of the subject, M. Boussingault concluded that plants have not the power of assimilating the free nitrogen of the atmosphere.

Experiments on the subject were commenced at Rothamsted in 1857, they were continued for several years, and the late Dr. Pugh took a prominent part in the enquiry.

The soils used were ignited, washed, and re-ignited pumice, or soil. The specially made pots were ignited before use, and cooled over sulphuric acid under cover. Each pot, with its plants, was enclosed under a glass shade, which rested in the groove of a specially made hard-baked glazed stoneware lute-vessel, mercury being the luting material. Under the shade, through the mercury, passed one tube for the admission of air, another for its exit, and another for the supply of water or solutions to the soil; and there was an outlet at the bottom of the lute-vessel for the escape of the condensed water into a bottle affixed for that purpose, from which it could be removed and returned to the soil at pleasure.

A stream of water being allowed to flow into a large stone-ware Woulff's bottle, of more than 20 gallons capacity, air passed from it, through two small glass Woulff's bottles containing sulphuric acid, then through a long tube filled with fragments of pumice saturated with sulphuric acid, and lastly through a Woulff's bottle containing a saturated solution of ignited carbonate of soda; and, after being so washed, the air entered the glass shade, from which it passed, by the exit tube, through an eight-bulbed apparatus containing sulphuric acid, by which communication with the unwashed external air was prevented. Carbonic acid was supplied as required by adding a measured quantity of hydrochloric acid to a bottle containing fragments of marble, the evolved gas passing through one of the bottles of sulphuric acid, through the long tube, and through the carbonate of soda solution, before entering the shade.

It will be observed that, by the arrangement described, the washed air was forced, not aspirated, through the shade, and the pressure being thus the greater within the vessel, the danger of leakage of unwashed air from without inwards was lessened.

In 1857, twelve sets of such apparatus were employed; in 1858 a larger number, some with larger lute-vessels, and shades; in 1859 six, and in 1860 also six.

Each year the whole were arranged, side by side, on stands of brickwork in the open air, as shown in the drawings of the apparatus exhibited. Drawings of some of the plants grown were also exhibited; and the numerical results obtained in the experiments of 1857 and 1858 are summarised in Table I.

The upper part of the Table (I.) shows the results obtained in 1857 and 1858, in the experiments in which no combined nitrogen was

supplied beyond that contained in the seed sown. The drawings exhibited showed how extremely restricted was the growth under these conditions, and the figures in the Table show that, neither with the Graminese, the Leguminosæ, nor the Polygoneæ (buckwheat), was there in any case a gain of three milligrams of nitrogen. In most cases there was much less gain than this, or a slight loss. There was, in fact, nothing in the results to lead to the conclusion that either of these different descriptions of plant had assimilated free nitrogen.

TABLE I.

Summary of the Results of Experiments made at Rothamsted, in 1857 and 1858, to determine whether plants assimilate free Nitrogen.

				Nitrogen, Grams.		
				In Seed, and Manure if any.	In Plants, Pot, and Soil.	Gain or Loss.
WITH NO COMBINED NITROGEN SUPPLIED BEYOND THAT IN THE SEED SOWN.						
Graminese	1857	Wheat		0·0080	0·0072	— 0·0008
		Barley		0·0056	0·0072	+ 0·0016
		Barley		0·0056	0·0082	+ 0·0026
	1858	Wheat		0·0078	0·0081	+ 0·0003
		Barley		0·0057	0·0058	+ 0·0001
		Oats		0·0063	0·0056	— 0·0007
	1858 A*	Wheat		0·0078	0·0078	0·0000
		Oats		0·0064	0·0063	— 0·0001
Leguminosæ	1857	Beans		0·0796	0·0791	— 0·0005
	1858	Beans		0·0750	0·0757	+ 0·0007
		Peas		0·0188	0·0167	— 0·0021
Other Plants	1858	Buckwheat		0·0200	0·0182	— 0·0018
WITH COMBINED NITROGEN SUPPLIED BEYOND THAT IN THE SEED SOWN.						
Graminese	1857	Wheat		0·0329	0·0383	+ 0·0054
		Wheat		0·0329	0·0331	+ 0·0002
		Barley		0·0326	0·0328	+ 0·0002
		Barley		0·0268	0·0337	+ 0·0069
	1858	Wheat		0·0548	0·0536	— 0·0012
		Barley		0·0496	0·0464	— 0·0032
		Oats		0·0312	0·0216	— 0·0096
	1858 A*	Wheat		0·0268	0·0274	+ 0·0006
		Barley		0·0257	0·0242	— 0·0015
		Oats		0·0260	0·0198	— 0·0062
Leguminosæ	1858	Peas		0·0227	0·0211	— 0·0016
		Clover		0·0712	0·0665	— 0·0047
	1858 A*	Beans		0·0711	0·0655	— 0·0056
Other Plants	1858	Buckwheat		0·0308	0·0292	— 0·0016

* These experiments were conducted in the apparatus of M. G. Ville.

The lower part of the Table shows the results obtained in the experiments in which the plants were supplied with known quantities of combined nitrogen, in the form of a solution of ammonium-sulphate, applied to the soil. The drawings show very strikingly the effect of this direct supply of combined nitrogen, especially in the case of the Graminese. The figures in the Table show that the actual gains or losses of nitrogen range a little higher in these experiments, in which larger quantities were involved; but they are always represented by units of milligrams only, and the losses are higher than the gains. Further, the gains, such as they are, are all in the experiments with the Graminese, whilst there is in each case a loss with the Leguminosæ, and with the buckwheat. The losses, beyond such as might be expected from experimental error, are doubtless due to decay of organic matter, fallen leaves, &c.

It should be stated that the growth was far more healthy with the Graminese than with the Leguminoseæ, which are, even in the open field, very susceptible to vicissitudes of heat and moisture, and were found to be extremely so under the conditions of enclosure under glass shades. It might be objected, therefore, that the negative results with the Leguminosæ are not so conclusive as those with the Graminese. Nevertheless, we concluded, and still conclude, from the results of our own experiments, as Boussingault did from his, that neither the Graminese nor the Leguminosæ assimilate the free nitrogen of the air.

That, under the conditions described, the Leguminosæ, as well as the Graminese, can take up and assimilate already combined nitrogen supplied to them, is well illustrated in the experiments made in 1860 with Leguminosæ alone. The series comprised three experiments with white Haricot beans—No 1 without any other supply of combined nitrogen than that in the seed, No. 2 with a fixed quantity of nitrogen applied as ammonium sulphate, and No. 3 with a fixed quantity supplied as nitrate; also 3 experiments with white Lupins—No. 1, as with the Haricots, without artificial supply of combined nitrogen, No. 2 with supply as ammonium-sulphate, and No. 3 as nitrate.

The drawings clearly showed that, with both descriptions of Leguminous plant, there was considerably increased growth by the addition both of ammonium sulphate and of nitrate. Owing, however, to the atmospheric conditions within the shade, as above referred to, the plants lost both leaves and flowers, and hence the drawings do not represent the full growth.

Such, then, were the negative results obtained when plants were grown under conditions of sterilisation and of enclosure. There was, under such conditions, no gain from free nitrogen, in the growth of either Graminese, Leguminosæ, or other plants.

RECENT EXPERIMENTS, WHICH DO SHOW FIXATION OF FREE NITROGEN.

I stated in my lecture last year, that it was about 1876 that M. Berthelot called in question the legitimacy of the conclusion that

plants do not assimilate the free nitrogen of the air, when drawn from the results of experiments in which the plants are so enclosed as to exclude the possibility of electrical action, and that he had more recently objected to experiments so conducted with sterilised materials, on the ground that, under such conditions, the presence, development, and action, of micro-organisms are excluded. It was pointed out that in the experiments of Berthelot, and some others, gains were found under very various conditions, that they were in some cases very small, and in others very large, and that the explanations of the gains were very various. I believe, however, that there is nothing in the recent results, either of Berthelot himself or of others, which can be held to invalidate the conclusion which had been drawn from the results of Boussingault, and from those obtained at Rothamsted, that the higher chlorophyllous plants do not directly assimilate free nitrogen.

Let us now consider what are the results obtained, when the conditions of growth involve neither sterilisation nor enclosure.

We have maintained that it can hardly be said that there remained an unsolved problem in regard to the source of the nitrogen of our *non*-Leguminous crops, but that it must be admitted, in spite of all the investigations and discussions of the last 50 years, that the source of the whole of the nitrogen of our Leguminous crops had not been satisfactorily explained. Hence, it was argued, evidence obtained on new lines should receive careful consideration. According to some recent experimenters, however, gain from the fixation of free nitrogen is not limited to our Leguminous crops. But, quite accordantly, not only with common experience in agriculture, but with the direct experimental results of ourselves and others, Hellriegel found in his experiments that plants of the gramineous, the chenopodiaceous, the polygonous, and the cruciferous families, depended on combined nitrogen supplied within the soil. On the other hand, he found that leguminous plants did not depend entirely on such supplies. His results were, indeed, not only very definite, but they had a special bearing on the admittedly unsolved problem of the source of the whole of the nitrogen of the Leguminosæ.

Accordingly, as already stated, we made experiments on the subject at Rothamsted in 1888 and 1889, and it is being further investigated in the present season, 1890. I propose to give, on the present occasion, a description, and some of the numerical results, of the experiments made in 1888; a description, and some illustrations of the growth, in 1889; and also a brief account of the experiments still in progress.

Hellriegel's experiments may be briefly described as follows:—in 1883 he commenced a comprehensive series of vegetation experiments in pots, in which he grew agricultural plants of various families in washed quartz sand. To all the pots nutritive solutions containing no nitrogen were added. To one series nothing else was supplied; to a second a fixed quantity of nitrogen as sodium-nitrate; to a third twice as much; and to a fourth four times as much. The result was that, in the case of the Graminæ, and some other plants, the growth was

largely proportional to the nitrogen supplied, whilst in that of the Papilionaceæ it was not so. In the case of these plants, that of peas for example, it was observed that, in a series of pots to which no nitrogen was added, most of the plants were apparently limited in their growth by the amount of nitrogen which the seed supplied. Here and there, however, a plant growing under ostensibly the same conditions, grew very luxuriantly; and, on examination, it was found that whilst no nodules were developed on the roots of the plants of limited growth, they were abundant on those of the luxuriantly growing plants.

In view of this result, Hellriegel instituted experiments to determine whether, by the infection of the soil with appropriate organisms, the formation of the root nodules, and luxuriant growth, could be induced, and whether by the exclusion of such infection the result could be prevented. To this end, he added to some of a series of experimental pots 25 cc., or sometimes 50 cc., of the turbid extract of a fertile soil, made by shaking a given quantity of it with five times its weight of distilled water. In some cases, however, the extract was sterilised. In those in which it was not sterilised, there was almost uniformly luxuriant growth, and abundant formation of root nodules; but with sterilisation there was no such result. Consistent results were obtained with peas, vetches, and some other Papilionaceæ; but the application of the same soil-extract had no effect in the case of lupins, serradella, and some other plants of the family which are known to grow more favourably on sandy than on loamy or rich humus soils. Accordingly, he made a similar extract from a diluvial sandy soil where lupins were growing well, in which it might be supposed that the organisms peculiar to such a soil would be present; and, on the application of this to a nitrogen-free soil, lupins grew in it luxuriantly, and nodules were abundantly developed on their roots.

THE VEGETATION EXPERIMENTS IN 1888.

This preliminary series comprised experiments with peas, blue lupins, and yellow lupins. The peas were grown—

1. In washed sand, with the ashes of the plant added; but with no supply of combined nitrogen beyond a small determined amount in the washed sand, and that in the seed sown.
2. In similarly prepared sand, but seeded with 25 cc. of the turbid watery extract from a rich garden soil.
3. Duplicate of No. 2.
4. In the rich garden soil itself.

Each of the two descriptions of lupins was grown—

1. In sand prepared as for the peas, but with the lupin-plant-ash instead of pea-plant-ash added.

2. In similar washed sand, &c., but seeded with 25 cc. of the turbid watery extract from a sandy soil where lupins had grown luxuriantly.
3. In the lupin sandy soil itself.
4. In rich garden soil.

The twelve pots were arranged in a small greenhouse; and distilled water, free from ammonia, was used for watering.

The sand employed was a yellow sand, from Flitwick, in Bedfordshire, such as is used by gardeners for potting. The stones and coarser portions were removed by sifting, the remainder was several times washed, first with well-water, and afterwards with distilled; then dried in a water-bath, and finally mixed with the plant-ash. It still contained 0·00266 per cent. of nitrogen.

The sandy-soil from which the watery extract was made for microbe-seeding the pots where lupins were to grow, and which was used as the soil in experiment No. 3 with lupins, was obtained from land which had been reclaimed from a common in Suffolk, on which no corn crop would grow, but on which, when subsequently sown with blue lupins they grew as high as the hurdles. Excepting that visible organic matter was removed by sifting and picking, it was used as received, in which state it contained 0·0859 per cent. of nitrogen.

The garden-soil contained 10·12 per cent. of moisture, and 0·3919 per cent. of nitrogen, corresponding to 0·4360 per cent. on the soil dried at 100°C.

The pots used were made of glazed earthenware. They had a hole half an inch in diameter at the bottom for drainage, and another at the side, near the bottom, for aëration, into which a glass tube bent upwards, and lightly closed with cotton wool to exclude insects, was fixed. The pots rested on slips of thick sheet glass, placed in basins of the same glazed earthenware as the pots.

The plant-ashes used as mineral nutriment, were prepared by suspension in distilled water, adding sulphuric acid to the point of neutralisation, evaporating to dryness, and gently re-igniting.

The drain hole at the bottom of each pot was loosely covered with a piece of thick glass, and 1 lb. of broken, washed, and dried flint was then put in. The pots held from 7 to 9 lbs. of the yellow sand, from 6 to 7 lbs. of the lupin sand, and about 4½ lbs. of the garden soil.

The soil extracts supposed to supply the organisms were made by shaking, in a stoppered bottle, 1 part of the garden soil or lupin sand, with 5 parts of distilled water, and, after subsidence, pouring off the turbid liquid, which was then passed through platinum gauze to separate any floating matter. Determinations of nitric nitrogen by Schlæsing's method, and of total nitrogen by copper-oxide, showed that the 25 cc. of the garden-soil extract used for seeding contained little more than ¾ of a milligram, and the 25 cc. of the lupin sand extract, little more than ¼ of a milligram, of nitrogen; quantities which are quite immaterial considered as a supply of combined nitrogen.

The seeds were selected for sowing and for analysis by weighing 3 or 4 lots of 100 each to ascertain the average weight per seed, and then a number of single seeds weighing within 5 milligrams of the mean weight were taken.

It was intended to commence the experiments early in the summer; but owing to the pressure of other work the necessary preparations were not completed until early in August. All the seeds were sown on August 6; 3 accurately weighed seeds being put into each pot.

From the first the peas germinated and grew well in each of the 4 pots; but in each of the 4 of blue lupins, and in each of the 4 of yellow lupins, one or more seeds failed, and had to be replaced; and in some cases these also failed. It is admittedly very difficult to secure healthy growth with lupins in pots. One essential condition seems to be that the soil must be kept open and porous; and it is also important that the mineral matter added to the soil should be quite neutral.

The failures with the lupins are well illustrated by the fact that, in spite of the re-sowings, there were, eventually, of blue lupins 3 plants in pot 1 with the yellow sand without soil-extract seeding; only 2 in pot 2 with the same sand and soil-extract seeding; none in pot 3 with the lupin sand itself, from which the soil-extract was prepared; and 3, but of very varying size, in pot 4 with garden-soil.

Then of yellow lupins there were only 2 plants in pot 1 with the yellow sand; only 2 in pot 2 with the sand and the lupin soil-extract seeding; only 2 in pot 3 with the lupin sand itself; and only 2 in pot 4 with the garden-soil.

Thus, in the preliminary experiments of 1888, with neither blue nor yellow lupins was the growth satisfactory; whilst, as will be seen further on, it was far otherwise, at any rate with yellow lupins, in 1889. I will not, therefore, take up time with any detailed discussion, either of the growth, of the root-development, or of the analyses, of the lupins of 1888; but I will now direct attention to the more satisfactory results obtained with peas in 1888, which, it will be seen, afford very important indications.

The Results with Peas, in 1888.

As already said, the peas in each of the four pots germinated and grew well. Those in the garden-soil were throughout the most luxuriant. Pots 2 and 3 were each seeded with 25 cc. of the garden-soil extract on August 13, that is just a week after the sowing of the seed.

For some time the plants in pot 1, in the sand without soil-extract, showed more growth, and better colour, than those in either pot 2 or pot 3 with the soil-extract seeding. It was, in fact, not until four or five weeks after the seeding with the soil extract, that the plants in pots 2 and 3 began to show a darker green colour than those in pot 1 without soil-extract. The indication was, however, so striking that, on September 25, it was decided to count the leaves, and to estimate, approximately, the relative area of leaf-surface, of the plants in the different pots. For this purpose the leaves were classified into those

which were bright green, those which were changing colour, and those which were withered. It will suffice to show the number, and the estimated relative area, of the total leaves in each case, on September 25, when the first counting and estimates were made, on October 17, on November 14, and on December 14 when the plants were cut. The following table summarises the results.

TABLE II. PEAS, 1888.

Total number of leaves, and estimated relative leaf surface, those of the plants in Pot 1 (without soil-extract seeding) on September 25, being taken as 100.

	Number of leaves.				Estimated relative leaf surface.			
	Pot 1	Pot 2	Pot 3	Pot 4	Pot 1	Pot 2	Pot 3	Pot
September 25..	144	140	120	164	100	67	58	128
October 17 ..	188	200	184	216	143	172	158	242
November 14..	244	300	244	280	170	249	245	328
December 14..	382	540	390	434	267	481	434	463

Thus, on September 25, after the plants in pots 2 and 3, with the soil-extract seeding, had begun to show a darker green colour, they nevertheless showed both a less number of leaves, and considerably less leaf-surface, than the plants in pot 1 without the soil-extract. It is not very clear why the plants with the soil-extract seeding remained so long in a comparatively backward condition. It may have been only accidental, depending on the character of the seeds, or on the fact that pot 1 stood at the southern end of the row, and nearest the glass. An alternative is that, in the early stages of the development of the nodules and their contents, the growth of the higher plant is in some way retarded. The figures show, however, that from this date, the plants in pots 2 and 3 with the soil-extract, gradually gained upon those in pot 1 without it, both in number of leaves and in leaf-surface; until, when the plants were taken up on December 14, those in pots 2 and 3 showed 540 and 390 leaves, against only 382 on those in pot 1; and 481 and 434 of leaf-surface, against only 267 in pot 1. There is, therefore, clear evidence of increased growth under the influence of the soil-extract seeding.

In all the pots the upper portions of the plants obviously developed at the expense of the lower, the leaves of which gradually lost colour, and withered, whilst the stems and leaves of the upper portion increased in growth; those in pots 2, 3, and 4, continuing to vegetate and to maintain a bright green colour to the last, whilst those in pot 1 showed more exhaustion, and maintained much less colour. Probably owing to the lateness of the season, there was no indication of flowering in any of the pots.

As the roots had to be preserved without any loss, for analysis, the examination of them had to be very carefully conducted, and was necessarily more restricted than if examination had been the only object. After the above-ground growth had been cut off, the pots, with their moist soil and roots, were kept in a warm dry place until the

examination commenced. The block of soil was carefully turned out on to glazed cartridge paper, and notes were at once taken as to the distribution of roots so far as it was then apparent. The sand or soil was then removed little by little until the roots were left nearly bare. Further notes were then taken, the remaining sand or soil was removed as far as possible by washing in a beaker with a little distilled water. The roots were then spread out upon paper, and so photographed, and finally noted upon.

The four pots of plants were photographed on September 1, September 22, October 6, and lastly on November 3, about five weeks before the taking up of the plants. Enlarged photographs of the plants at the last mentioned date, and of the roots when taken up as above described, were exhibited.

When due allowance is made for the difference in colour of the stems and leaves, as above described, the photographs of the plants are consistent in their indications with the results given in Table II., and with those which follow as to the relative amounts of dry matter produced, and of nitrogen taken up.

The indications of the enlarged photographs of the roots of the plants are of much interest.

The roots in pot 1, with the washed but not sterilised yellow sand, showed a densely matted mass of fibre, by far the greater portion of which was accumulated within the top four inches of the sand; and, notwithstanding there was no soil-extract seeding, there were many nodules on the roots, but fewer, and generally much smaller, than on those grown with the soil-extract seeding; they were also less characteristically accumulated near the surface, and more distributed along the root fibres. There were, however, some agglomerations of nodules. Comparing this result with that obtained in 1889, with a purer and sterilised sand, in which case there were no nodules, there can be little doubt that the development of nodules, and the comparatively luxuriant growth, in this pot without soil-extract seeding, are to be attributed to the impurity and non-sterilisation of the sand.

The roots in pot 2, with soil-extract seeding, also showed a dense mass of fibre, which, however, extended from the top to the bottom of the soil, penetrated the layer of flints, and distributed over the bottom of the pot. The roots were, in fact, much more generally distributed throughout the soil, and less accumulated within the surface layers, than in pot 1. The most developed root had three large agglomerated nodules, each with some scores of protuberances, somewhat as on a raspberry or mulberry. The other plants also showed similar nodules, but of a smaller size. There were also a number of small clusters distributed over the rootlets, but very few single nodules; differing in this respect from the development observed in pot 1.

In pot 3, also with soil-extract seeding, each of the three plants developed a mass of root-fibre extending throughout the soil, but less near the bottom. There were large agglomerations of nodules on the roots of each plant. There were, besides, many small clusters, and here

and there single nodules. By far the most of the nodules were within the top three inches of the sand, but one considerable bunch was found as low as four inches from the surface. As in the other cases, the nodules were grey, and much lighter in colour than the roots on which they grew.

Each of the three plants in pot 4, with the garden soil, had a stouter main root than any of those in the other pots. From the side branches there proceeded a large amount of fine root-fibres which extended throughout the whole soil, those from the different plants being much interwoven. The roots extended round the sides, and along the bottom of the pot, much more than in either of the other pots. There were three small clusters of nodules on the roots of each of the three plants, one or two small bunches, and here and there a single nodule. But the clusters were much smaller, the total number of nodules was much less, and they were more distributed throughout the soil, in this pot with rich garden soil, than in either of the others, even than in pot 1 without soil-extract seeding. The root development was, however, as the description shows, much greater than in either of the other pots. That is to say, there was, in this case, not only a greater development of root and root-fibre, but a less development of root nodules, in the soil which itself supplied an abundance of combined nitrogen, as well as other nutriment.

Upon the whole, then, the evidence relating to the peas clearly shows that there was a greatly enhanced development of nodules on the roots under the influence of the soil-extract seeding, and, coincidently with this, considerably increased growth.

The Analytical Results.

The nitrogen was determined in the sand and in the garden soil, at the commencement and at the conclusion of the experiments; also in the seed, in the above-ground growth (stems and leaves), and in the roots, separately. The dry matter and ash were also determined, in the seed, and in the produce grown.

It is of interest to remark, that the percentage of ash in the dry substance of the more normally developed plants grown in the garden soil, was much less than in that of the plants grown in the sand with plant-ash added; also that the plants in pot 1, with the most restricted growth, and which from their pale colour indicated nitrogen-exhaustion, showed a lower percentage of nitrogen in the dry substance of both the above-ground and under-ground produce, than was found in that of either of the other pots. It may be added that the roots in pots 2 and 3, with the soil-extract, and with so much greater development of nodules than on those in either pots 1 or 4, also contained a considerably higher percentage of nitrogen in their dry substance.

The next Table (III.), shows the actual quantities of dry substance, and of nitrogen, in the separated, and in the total, products of growth.

It is seen that there is more dry substance in the above-ground growth, but less remaining in the roots, in pots 2 and 3 with the soil-

extract, than in pot 1 without it. In the whole plant, there is about 10 grams of dry substance in pot 1 without soil-extract, against about 11½ grams in pot 2, and more than 11 grams in pot 3, each with soil-extract.

TABLE III. PEAS, 1888.

	Dry Substance.			Nitrogen.		
	In stems and leaves.	In Roots.	In whole plant.	In stems and leaves.	In Roots.	In whole plant.
	grams.	grams.	grams.	gram.	gram.	gram.
Pot 1. Sand without soil-extract	7·423	2·600	10·023	0·2153	0·0669	0·2822
Pot 2. Sand with soil-extract	9·368	2·409	11·777	0·4591	0·0770	0·5361
Pot 3. Sand with soil-extract	9·411	1·748	11·159	0·3770	0·0587	0·4357
Pot 4. Garden soil	12·808	2·846	15·654	0·5806	0·0794	0·6600

The point of chief interest is, however, that there was in one case more than twice, and in the other nearly twice, as much nitrogen in the above-ground growth in pots 2 and 3 with the soil-extract seeding, as in pot 1 without it. But there was much less difference in the amounts remaining in the roots under the different conditions. Of nitrogen in the total vegetable matter grown, there is, in pot 2 nearly twice, and in pot 3 more than 1½ time as much as in pot 1 without the soil-extract. In pot 4 with garden soil, and therefore full supply of already combined nitrogen, there was more dry substance produced, and more nitrogen assimilated, than under the influence of the soil-extract seeding.

The significance of the results relating to the nitrogen is, however, more clearly seen in the next Table (IV.), which shows—the amounts in the soil at the commencement and at the conclusion of the experiment, and the gain or loss; the amounts in the seed, in the total products of growth, and the gain; the total nitrogen in the soil and seed at the commencement, in the soil and produce at the conclusion, and the gain. The Table also shows, in the last column but one—the nitrogen in the total products reckoning the total initial nitrogen = 1; and in the last column, the amount in the plants, reckoning that in the seed = 1.

TABLE IV. PEAS, 1888.

	Nitrogen.										
	In Soil.			In Seeds and Produce.			Total.			In total products, total initial = 1.	In plants, Nitrogen in seed = 1.
	At commencement.	At conclusion.	Gain (+) or loss (−)	In Seeds Sown.	In total Plants.	Gain.	At commencement.	At conclusion.	Gain.		
	grams.	grams.	gram.	gram.	gram.	gram.	grams.	grams.	gram.		
Pot 1	0·0999	0·1096	+ 0·0097	0·0293	0·2822	0·2529	0·1292	0·3918	0·2626	3·03	9·63
Pot 2	0·0999	0·0974	− 0·0025	0·0298	0·5361	0·5063	0·1297	0·6335	0·5038	4·88	17·99
Pot 3	0·0999	0·0848	− 0·0151	0·0291	0·4357	0·4066	0·1290	0·5205	0·3915	4·04	14·97
Pot 4	7·9989	7·9989	—	0·0301	0·6600	0·6299	8·0290	8·6589	0·6299	1·08	21·93

The first point to notice is, that there is very little difference in the amount of nitrogen in the soils at the commencement and at the conclusion of the experiments. There would, doubtless, be some fine root-fibre not removed at the conclusion, so that where there is loss it is to be supposed that some of the original nitrogen of the soil has contributed to the growth. In the case of the garden-soil, with its high percentage of nitrogen, it is of course not impossible that there may have been some loss by the evolution of free nitrogen.

That there is at any rate no material gain of nitrogen in the soils would seem to be confirmatory of the conclusion indicated by other evidence, that the fixation is not effected by the organisms within the soil, independently of the symbiotic growth of the nodules and their contents, and of the higher plant to which they are attached, and to whose nitrogenous supply they seem to contribute. Indeed, if the fixation had taken place under the influence of microbes within the soil, independently of connexion with the higher plant, we should have to conclude that the latter had, nevertheless, availed itself of exactly the whole of the nitrogen so brought into combination—a supposition for which there would seem no reasonable justification.

Turning to the middle division of the Table, which shows the nitrogen in the seed sown, in the total vegetable matter grown, and the gain, and disregarding the changes in the soil itself, which it has been seen may well be done, it will be observed that, in the case of pots 1, 2, and 3, with sand, the gain in the plants is so large as to be very far beyond the limit of any possible experimental error. This certainly cannot be said of some of the experiments conducted on other lines, the results of which have been published in recent years, and have been held to show the fixation of free nitrogen under the agency of micro-organisms within the soil, without coincident higher plant-growth, or with the coincident growth of other plants than of the Leguminous family.

The gain in these initiative experiments with peas is, however, much less than in many of those of Hellriegel and Wilfarth. This is not to be wondered at, when the late period of the season, and the consequent character of the growth, are borne in mind; and when we come to consider the greater growth attained in the experiments of 1889, little doubt can be entertained that the fixation was then very much greater than it was in 1888.

To refer to the figures, it is seen that, whilst the nitrogen supplied in the seed was only 0·03 gram or less, that in the products of growth was 0·2822 gram in pot 1, 0·5361 in pot 2, 0·4357 in pot 3, and 0·6600 in pot 4; and the gains were more than $\frac{1}{4}$ of a gram in pot 1, more than $\frac{1}{2}$ a gram in pot 2, about $\frac{3}{5}$ths of a gram in pot 3, and more than $\frac{2}{3}$ths of a gram in pot 4.

The third division of the table shows—the total nitrogen at the commencement (in soil and seed together), at the conclusion (in soil and total vegetable matter grown), and the gains.

But the significance of the results is more clearly seen in the last

two columns. The first of these shows the relation of the amount of nitrogen in the total products (soil and plants together), to the total initial nitrogen (soil and seed together), taken as 1. It is seen that, even in pot 1, with the impure and not sterilised sand, but without soil-extract, there was, so reckoned, more than three times as much nitrogen in the products as in the soil and seed; in pot 2, with soil-extract, there was nearly five times as much; and in pot 3, also with soil-extract, there was more than four times as much. In the case of pot 4, however, with garden soil, owing to the large amount of initial nitrogen in the soil, the gain, though actually large, appears, when so reckoned, but small.

It is in the last column of the table, in which, disregarding the nitrogen in the soils, which was so nearly the same at the beginning and at the end, and reckoning the relation of the nitrogen in the total products of growth to that in the seed taken as 1, that the large amount of fixation is clearly brought to view. So reckoned, the nitrogen in the substance grown to that in the seed sown, was—in pot 1, 9½ fold; in pot 2, nearly 18 fold; in pot 3, nearly 15 fold; and in pot 4, nearly 22 fold.

Here, then, under non-sterilised conditions, in fact with suitable microbe infection, there was very considerable fixation of free nitrogen.

THE VEGETATION EXPERIMENTS IN 1889.

In this second season a more extensive series was arranged. The plants selected were—peas, vetches, red clover, blue lupins, yellow lupins, and lucerne. For the lupins and lucerne, specially made pots of glazed earthenware were employed. They were about 6 inches in diameter, and 15 inches deep inside, that is about twice as deep as those used in 1888, and again for the peas, vetches, and red clover, in 1889. These pots had holes at the bottom for drainage, and slits at the side, near the bottom, for aëration. Each of the pots stood in a specially made pan of the same material. A quantity of broken, washed, and this time ignited flint, was put into the bottom of each pot. The sand used was a rather coarse, white quartz sand, from which the coarser and the finer portions were removed by sifting, and more of the finer by washing and decantation, first with well, and afterwards with distilled, water. In defect of means for igniting so large a quantity of material (about 300 lbs. in all) without running the risk of gaining more impurity than was expelled, the portion retained for use was kept, in successive lots, in a large water-bath, at nearly 100°C, for several days, and then preserved in well closed bottles. The results will show that the sand so prepared was sufficiently, if not absolutely, sterilised.

In each case the sand was mixed with 0·1 per cent. of the plant ash, and 0·1 per cent. of calcium carbonate; though much smaller quantities have since been used.

There were four pots of each description of plant. Of the peas,

vetches, red clover, and lucerne, No. 1 was with the prepared quartz sand without soil-extract; No. 2 with the quartz sand and garden-soil-extract added; No. 3 was duplicate of No. 2; and No. 4 was with the garden-soil itself. Of the blue and yellow lupins, No. 1 was with the prepared quartz sand without soil-extract; No. 2 with lupin-soil-extract added; No. 3 was duplicate of No. 2; and No. 4 was with the lupin soil itself, to which 0·01 per cent. of the plant-ash was added.

The soil-extracts were added the day before the sowing of the seed; 25 cc. in the case of the peas, vetches, and red clover, and 50 cc. in that of the lupins and lucerne.

The seeds, selected and weighed as in 1888, were sown on July 10, that is, about four weeks earlier than in 1888, but still not so early as was desirable. In the case of the red clover ten seeds were sown in each pot; in that of the blue and yellow lupins three, and in that of the peas, vetches, and lucerne, only two seeds, were put in each pot.

In all four pots, the peas germinated and grew well from the beginning. In the No. 1 pot of vetches, one seed failed, and had to be replaced. Several of the red clover seeds failed, and eventually four plants only were left in each pot. As in 1888, most of the blue lupins failed, and eventually only one plant, in only one of the four pots, remained. Some of both the yellow lupins and the lucerne also failed; but, as will be seen further on, eventually two good plants remained in each pot.

The analytical details relating to the experiments of 1889 are not yet available; but the notes on growth, and the photographs of the plants and of their roots, convey a clear idea of the importance and significance of the results obtained.

The Experiments with Peas, in 1889.

The peas were taken up on October 23 and 24. Photographs of the four pots of plants were taken on August 3, August 20, September 27, and lastly on October 22, that is the day before taking up; and an enlargement of the last taken was exhibited. Unlike the result obtained in pot 1 in 1888 with impure and non-sterilised sand, the plants of 1889, in the purer and sterilised quartz sand, showed extremely limited growth. Before the end of July, those in both pots 2 and 3, with soil-extract seeding, began to show enhanced growth compared with that in pot 1, without the soil-extract; and, eventually, whilst the plants in pot 1 were only $8\frac{1}{4}$ and $8\frac{1}{2}$ inches in height, those in pot 2, with soil-extract, were 14 and $50\frac{1}{2}$ inches; and those in pot 3, also with soil-extract, were $52\frac{1}{2}$ and $50\frac{1}{2}$ inches high. In pot 4, with the garden soil, the plants showed even somewhat less extended growth than those in pots 2 and 3 with the soil-extract only. But the plants in pot 4 were more vigorous, and whilst they flowered and seeded, neither of those in either pot 2 or pot 3 did so; but continued to vegetate, the upper parts apparently at the expense of the lower.

Then as to the root development:—in pot 1, without soil-extract, it

was altogether much less than in either pot 2 or pot 3 with soil-extract, or than in pot 4 with garden soil. Enlarged photographs of the roots clearly illustrated this. It was further seen that, in pot 1, without soil-extract seeding, the main roots descended some distance before they threw out any considerable amount of root-branches and root-fibre; whereas, in pots 2 and 3, with soil-extract, there was characteristically much more fibre distributed, both in the upper layers, and throughout the pot.

It is specially to be noted that, whereas in pot 1 in 1888, with impure and non-sterilised sand, there was a considerable development of nodules, now in the pure and sterilised sand, not a nodule was observable.

In pot 2, with soil-extract seeding, one plant was very much larger than the other, and developed very much more root. The smaller plant had, however, several nodules on the main root, near the surface of the soil, and a good many small ones distributed along the fibres. Most of the nodules were more or less shrivelled. The larger plant had a large cluster of nodules on the main root, very near the surface; and a very large number of single nodules, mostly small, was distributed on the root-fibres, quite to the bottom of the pot. Upon the whole those on the larger plant were less shrivelled.

In pot 3, also with soil-extract, the main roots extended to, and along, the bottom of the pot; throwing off many side branches, with a very large quantity of fine fibrous root. The greatest distribution was, however, in the upper few inches of the soil. There were two clusters of nodules on one of the plants, and three on the other, besides smaller bunches. A large number of mostly single small nodules was also distributed along the roots. On one of the plants the largest cluster was on the main root, and on the other the clusters were on the side branches.

In pot 4, with the garden soil, there was a dense mass of root-fibre throughout the first six inches of depth. There were numerous nodules, the majority single, and within the upper two or three inches of soil. There were also a few small bunches.

Thus, then, the limited growth in pot 1, without soil-extract, is coincident with the entire absence of nodule-formation; and the increased growth in pots 2 and 3, with soil-extract, is coincident with a very great development of nodules. In pot 4, with garden soil, itself supplying abundance of nitrogen, there was also a considerable development of nodules, but distinctly less than in either pot 2 or pot 3, with soil-extract only.

The Experiments with Vetches, in 1889.

The vetches were taken up on October 26. They had been photographed on August 3, August 20, September 27, and lastly on October 25, that is, the day before taking up; and of this last representation an enlargement was exhibited.

As with the peas, the plants in pots 2 and 3, with soil-extract, had, before the end of July, shown more growth than those in pot 1 without it. Again, as with the peas, the vetches in the pure and sterilised sand showed extremely limited growth. On the other hand, those in pots 2 and 3, with the soil-extract, grew to a very great height; indeed, higher than those in pot 4 with the garden soil.

The heights of the plants were—in pot 1, without soil-extract, 11¼ and 10½ inches; in pot 2, with soil-extract, 52½ and 67 inches; in pot 3, also with soil-extract, 61½ and 51 inches; and in pot 4, with garden soil, only 53 and 36 inches.

But, as in the case of the peas, whilst the plants in pot 4 with the garden soil flowered and seeded, those in pots 2 and 3, with the soil-extract only, did not, but continued to extend upwards at the expense of the lower parts of the plant.

In pot 1, without soil-extract, there was much less development of root than in either pot 2 or pot 3 with it, or than in pot 4 with the garden soil. The main roots descended to the bottom of the pot, and threw out a number of side branches, but there was a marked deficiency of root-fibre. Not a single nodule was found.

In pot 2, with soil-extract seeding, there was a dense mass of root and root-fibre, which distributed throughout the whole of the soil, though the greatest accumulation was within the first three inches of depth. There were numerous nodules, but considerably less in quantity than on the corresponding pea plants. They were mostly single, the greater number being found in the lower layers, which is also contrary to the result with the peas. They were, moreover, generally exceedingly small.

In pot 3, also with soil-extract, there was also an immense development of root and root-fibre through the whole area of the soil; the greatest accumulation being in the upper and lower portions of the pot, with less in the middle. There were many nodules, but very small, and probably fewer than on the roots in pot 2. All the nodules were single, and fairly distributed over the whole root area.

In pot 4, with garden soil, there was a moderate amount of root and of root-fibre, chiefly within the upper six inches of depth; but there was altogether very much less of root development than in either pot 2 or 3 with the soil-extract. There were many nodules, but all single, and very small; and they appeared to be flattened, as if exhausted of their contents.

Here, then, with the vetches, as with the peas, the very restricted growth in pot 1, without soil-extract seeding, was associated with very limited root development, and with the entire absence of nodule-formation. On the other hand, the very greatly extended vegetative growth in pots 2 and 3, with soil-extract, was associated with an immense development of root and root-fibre, extending throughout the pots, and with the formation of numerous nodules; which, however, were generally smaller, more distributed over the whole root area, and less accumulated near the surface, than in the case of the peas. Lastly,

in the garden soil, with its liberal supply of combined nitrogen, there was much less development of roots, and less also of nodules, than in the pots with soil-extract only.

The Experiments with Lupins, in 1889.

It has already been said that most of the blue lupins failed; but it was with the yellow lupins that the most striking of all the results were obtained.

As in the case of the other plants, the yellow lupin seeds were put in on July 10, three being sown in each pot. There were some resowings, some seeds taken out, and, eventually, two plants were left in each pot. By the end of July, those in pots 2 and 3 with the lupin-soil-extract seeding, already showed more growth than those in pot 1 without it. Photographs were taken on August 3, August 20, September 27, October 28, and November 29; and the plants were cut on December 7. An enlargement of the photograph taken on October 28 was exhibited.

It was seen that the plants in pot 1, without soil-extract seeding, scarcely appeared over the rim of the pot, one being only about $1\frac{1}{2}$, and the other about $2\frac{1}{2}$ inches high. In pot 2, with lupin-soil-extract seeding, one plant was about 2 feet, and the other more than $1\frac{1}{2}$ foot high; both spreading much beyond the width of the pot. In pot 3, also with lupin-soil-extract seeding, one plant was more than 2 feet, but the other little more than 8 inches high. In fact, in both these pots with soil-extract seeding only, the plants showed considerably more development than those in pot 4 in the lupin-soil itself; one of these being only about 16, and the other about 18 inches high, and both less branching than those in pots 2 and 3.

Unlike the peas and vetches, the yellow lupins with soil-extract seeding only, flowered and podded freely. One plant in pot 2 had nine small pods; and one in pot 3, four large and three small ones. There were also in pot 4, with lupin-soil, on one plant five pods, and on the other six.

Thus, in the quartz sand with lupin-soil-extract seeding, the plants not only produced a great deal more vegetable matter than those in the lupin-sand itself, but they as freely flowered and seeded.

Examination, and the photographs of the roots of the plants showed that in pot 1, without soil-extract, and very restricted above-ground growth, there was coincidently very little root development. The main roots descended far down the deep pot almost without branching, but at the bottom a number of branches, and a mass of fibre were produced. The root-fibres were fleshy and succulent. No root swellings or nodules were found.

In pot 2, with the lupin-soil-extract seeding, there was, on the other hand, a very great development of root. Branches were thrown out throughout the whole length; and at their ends masses of fleshy fibrils were formed, which were thickly coated with root-hairs. On the

main root of one plant, 3 inches down, there was a large swelling or nodule the size of a field bean; 4 inches lower there were three smaller ones on a side branch; 10 inches down there were three as large as peas; and lower still there was another small swelling, more like the nodules found on other plants. The other plant had less root growth. One and a half inch down there was a swelling the size of a small pea; and 4½ inches lower there were three swellings, one as large as a bean, and the others about the size of a vetch seed. These swellings on the lupin-roots, which were all on the main roots or thicker branches, are very different in appearance from the nodules on the pea and vetch-roots. They are, as described, swellings, incasing the root where they grow.

In pot 3, also with the lupin-soil-extract seeding, one plant developed an immense amount of branching root, with a great deal of root-fibre, which extended throughout the whole soil, but to a greater degree in the lower than in the upper half of the pot. The main root was woody near the top. The lower root-fibres were fleshy, and thickly coated with root-hairs. There were several swellings or nodules on the main root below 5 inches; and lower down, on a root-branch, there were several swellings; there being in all twelve on this plant. On the smaller and more meagrely rooted plant, about 10 inches down, there were also two bunches of small nodules, and three single nodules; and a little lower, on a side branch, another small nodule.

With regard to the great development of root-hairs on the fine fibrils of the roots in both pots 2 and 3, with quartz sand and soil-extract seeding, it may be supposed that this was an effort to acquire mineral nutriment, in quantity commensurate with the large amount of nitrogen fixed, and so rendered available to the plant.

In pot 4, with the lupin-soil itself, the distribution of root was very different from that in pots 2 and 3, with the soil-extract only. The main root, at a depth of 2 inches, threw out many thread-like branches, at the end of each of which there was a bundle of fine fibre. The lower fibres became thicker, and were white and fleshy; but they were without the marked development of root-hairs observed in such abundance in pots 2 and 3. Most of the root was within six inches of the surface, and there seemed to be none below 14 inches. One to two inches from the surface, there were swellings on the main roots, which were less raised, but more spreading, than those on the roots in pots 2 and 3. There were also, on one side branch, six very small nodules.

To sum up in regard to the yellow lupins: Under the influence of the lupin-soil-extract seeding, the above-ground growth was not only very luxuriant, but the plants developed great maturing tendency, flowering and seeding freely. The development of the roots generally, and that of swellings or nodules on them, were also very marked; and there can be no doubt that the gain of nitrogen will be found to be very large. In pot 4, with the lupin-sand itself, which would supply a not immaterial amount of combined nitrogen, although the growth was normal, it was, both above-ground and within the soil, very much less

than in the pots with soil-extract only; and the development of nodules was also less. It is possible that the less growth in the lupin-sand itself, than in the quartz-sand with soil-extract only, was partly due to the much less porosity of the lupin-soil, especially when watered. At any rate, the results with the soil-extract only are very remarkable.

The Experiments with Red Clover, in 1889-'90.

As the main growth of red clover is in the second year, the four pots of it were left for this year's growth. There is, therefore, at present but little of definite result available, but there are some points of interest to notice.

A photograph of the plants taken on September 28 (1889), showed that the above-ground growth in pot 1, without soil-extract, was decidedly more than in either pots 2 or 3 with it; and from the amount of growth that has since developed it is pretty certain that there is more than will be accounted for by the amount of nitrogen supplied in the seed sown. As the soil-extract seeding in pots 2 and 3 appeared to be without effect, a second amount of extract, this time from garden soil where clover was growing well, was applied to pot 2 on September 4; but to pot 3 there was added instead, a solution of calcium nitrate, and this application was continued up to December 6, when, in all, 0·23 gram of nitrogen had been so applied.

The effect of the nitrate was almost at once very striking; there being considerably increased growth, and coincidently, increased depth of green colour. It was not, however, until many weeks later that the growth in pot 2, to which a second application of soil-extract had been made, became at all marked.

Two cuttings have been taken from each of the four pots, and the indication so far is that, in all, more dry substance has been produced in pot 2, with the second application of soil-extract, than in pot 3 with the nitrate. It remains to be seen what will be the final result. It should be added, and it is significant, that the amount of produce cut from pot 4, with garden soil, is many times as much as that from either of the other pots.

The Experiments with Lucerne, in 1889-'90.

In the case of lucerne, as in that of red clover, the main growth is subsequent to the first year, and hence the plants were left for further growth, indeed they are still growing.

The application of garden-soil-extract to the lucerne appeared to be entirely without effect up to the beginning of September (1889); the plants in pot 1 without soil-extract, and those in pots 2 and 3 with it, showing no difference, and apparently no progress. On September 4, therefore, pot 2 was re-seeded with soil-extract, this time from a soil growing lucerne; but to pot 3 a solution of calcium nitrate was added instead, and the application has been continued at intervals. As with the clover, so with the lucerne, the application of nitrate to pot 3 very soon

showed marked effect; and a photograph taken on December 23 shows that there was, up to that date, considerably increased growth, and this has continued up to the present time. For many weeks, however, the second application of soil-extract was without any apparent effect, but subsequently there has been increased growth, and increased depth of green colour.

In pot 1, without soil-extract, the growth has been stationary since the first few weeks after sowing, and no cutting has been taken. From pot 2, with the repeated soil-extract seeding, a cutting was taken on June 24 (1890); and from pot 3 with the nitrate, and from pot 4 with the garden soil, cuttings were taken on March 4, and on June 24. At present there has been rather more produce removed from pot 3 with the nitrate, than from pot 2 with the soil-extract; but from pot 4, as in the case of the clover, the garden soil has yielded considerably more than either the soil-extract or the nitrate.

Again, therefore, we have illustrated, the influence of soil supply of combined nitrogen on the growth of a leguminous plant; the result being very marked whether the supply was as ready formed nitrate, or in the condition of combination and association with other constituents as in rich soil. Not that there is any want of abundant evidence showing that Leguminosæ do take up nitrogen largely as nitrate; but, in view of recent results showing fixation under the influence of micro-organism seeding, it seems to be assumed by some that these plants probably depend for their nitrogen exclusively on such agency.

DIFFERENCE IN THE EXTERNAL CHARACTER OF LEGUMINOUS ROOT-NODULES.

The descriptions which have been given, have shown that the external appearance, and the distribution, of the root nodules, were very different in the case of the peas, the vetches, and the lupins. In that of the peas there were many of what may be called agglomerations of nodules, and comparatively few single ones distributed on the root-fibres. On the roots of the vetches, there were comparatively few agglomerations or bunches, and more single nodules, pretty widely distributed along the root-fibres. The lupin roots, on the other hand, showed tubercular developments very different from those on either the pea or the vetch roots. Indeed, at the period of examination, that is when the plants were nearly ripe, two apparently distinct kinds were observed; one of which, the most prevalent, has been spoken of as "swellings," and the other as "nodules." The "swellings" were chiefly on the main roots or the thicker branches; where they grew they encased the root entirely, and they had a shining and presumably impervious skin. The "nodules," on the other hand, were chiefly single, small, and distributed on the root-fibres.

Assuming that the so-called "swellings" (with their contents), on the roots of the lupins were the bodies which had exercised the functions of the "nodules" found on the roots of the other plants, it

is to be concluded that, after the very luxuriant growth, and the flowering and seeding, their function was so far at an end, and they had become suberised. The other bodies on the lupin roots, distinguished in the detailed description as "nodules," indicated too meagre development to have had much share in the great amount of assimilation that had been accomplished. On the other hand, the "swellings" which, as has been said, were all on the main roots or thicker branches, were certainly very characteristic of the roots of the lupin plants which attained the greatest growth; and, assuming that they with their contents were really the effective bodies, it must be supposed that they had been formed where they were found whilst the root was still young, and had grown with its growth. In favour of this supposition is the fact that the increased growth from the soil-extract seeding commenced quite early in the life of the plants.

The nodules on the roots of lucerne growing in the field were observed at different periods of the season in 1887, and again quite recently on plants taken from the field for that purpose. They are quite different in general external character from those on any of the other plants that have been examined at Rothamsted. Instead of being more or less rounded, they have more the appearance of shoots or buds, much longer than broad, sometimes single, but more often divided, or branched; there being generally two or three, and sometimes as many as twenty, or even many more, in a bunch, joined at the base. They have, so far, not been observed on the main root, but only on the root-fibres, and less near the surface than within the range of the subsoil. In some cases such a tuft or bunch will be at the end of a fine fibre, by which it is connected with the main root. As the season advances these bodies become shrivelled, and are in fact empty shells.

Among the Leguminosæ growing in the mixed herbage of grass land, in 1868 nodules were observed on the root-fibres of *Lathyrus pratensis*, especially near the surface of the soil; on the ultimate root-fibres of *Trifolium pratense*, and on the smaller rootlets of *Trifolium repens*.

In the case of red clover growing in rotation on arable land, an abundance of nodules has been found, both near the surface and at a considerable depth. They are generally more or less globular or oval. Some found on the main roots were more like "swellings" than attached tubercles, not, however, encasing the root, but only on one side. The greater number are, however, small, and distributed chiefly on the root-fibres. Evidence is, however, needed, as to any difference in character, or relative prevalence, at different periods in the life and growth of the plant, and under different conditions of soil, both so far as mechanical state and porosity, and richness or otherwise in available supplies of combined nitrogen, are concerned. To these points I shall refer again presently.

HOW IS THE FIXATION OF NITROGEN TO BE EXPLAINED?

Reviewing the whole of the results which have been brought

forward, there can be no doubt that they are abundantly confirmatory of those obtained by Hellriegel and Wilfarth, and that the fact of the fixation of free nitrogen in the growth of Leguminosæ under the influence of suitable microbe infection of the soil, and of the resulting nodule formation on the roots, may be considered as fully established.

It may be added, that B. Frank has continued his experiments on this subject; further that, in 1888, both M. Berthelot and M. Bréal made various experiments with Leguminosæ, and that their results also confirm those of Hellriegel and Wilfarth.

Admitting, then, the fact of fixation under the conditions described, the question still remains, how is it to be explained? Unfortunately, there is much yet to learn before a satisfactory answer can be given. Obviously we must know more of the nature and mode of life of the organisms which, in symbiosis with the leguminous plant, bring about the fixation of free nitrogen, before the nature of the action can be understood. As to the mode of life of these bodies, we owe much to the investigations of Marshall Ward, Prazmowski, Beyerinck, and others; but the facts which they have established so far, are insufficient to afford an adequate explanation of the phenomena involved.

It is, I think, a point of importance that it should be established, as it appears to be, that in the development of the parasite the cortex of the root of the host is penetrated, and so an intimate connexion between the two, indeed a symbiosis, is set up. Then there is abundant evidence that the nodules are very rich in nitrogen. So far as the facts at command go, it would seem that, in certain stages of their development, their dry substance may contain a much higher percentage of nitrogen than that of any part of the growing plant itself; and, in some cases at any rate, even higher than in that of the highly nitrogenous leguminous seed.

Whence comes this nitrogen? The views of those who have studied the histology and biology of the subject, without reference to quantitative chemical data, do not seem to be very clear or definite on the point. Thus, it has been assumed that the bacteria acquire their nutriment, including their nitrogen, from the protoplasmic cell-contents of the higher plant; and that, on the other hand, the contents of the bacteroid cells are resorbed. In other words, the plant utilises the substance of the bacteroids. It is obvious, however, that so far as the nitrogen of the bacteria is derived from the plant itself, the latter is not a gainer in a quantitative sense by its resorption.

It has further been assumed, that the activity of the process depends on the quantity of the nitrogenous compounds at the disposal of the roots; the tubercles developing unhindered, and becoming large and typical, in a soil rich in nitrogen, but attaining no great size in poorer soils. The source of the nitrogen of the bacteria is here supposed to be combined nitrogen in the soil. The experimental results which have been described clearly show, however, that the nodules may develop very plentifully in a nitrogen-free soil, and that

there may, under such conditions, be great gain of nitrogen if only the soil be suitably infected.

It is at the same time stated, that no decision is arrived at as to whether the nitrogen comes from nitrogen-compounds, or from the free nitrogen of the air, nor as to what advantage accrues to the bacteria and to the host plant respectively. It is, however, also stated, that the bacteria feed on the sap and cell-contents, whilst the plant obtains nitrogen by means of the bacteria. But, as I have already said, if the nitrogen of the bacteria is derived from the plant, it will itself be no gainer by resorbing it. Nor would there be any such actual gain of nitrogen in nitrogen-free soils as there undoubtedly is, if the source of the nitrogen, either of the parasite or of the host, were essentially the supplies of combined nitrogen within the soil.

Further, one assumption is, that the organisms become distributed in the soil, both during the life of the host and afterwards, and that the fixation takes place under their agency within the soil itself, rather than in the course of the development of the bacteria in symbiosis with the higher plant. Another assumption is, that the fixation takes place in the soil itself under the influence of microbes existing within it, and that the higher plant assimilates the resulting combined nitrogen. As bearing upon these points it may be observed that, in the experiments with peas in 1888, there was practically no gain of nitrogen within the soil itself, which it may be supposed there would have been if the fixation had taken place within it, and the host had acquired its gain from the compounds there produced. Indeed, the evidence at present at command certainly does not point to the conclusion that the gain of nitrogen by Leguminosæ under the influence of microbe infection of the soil, and nodule formation, is due to fixation by organisms within the soil itself, independently of the symbiotic life. It is admitted, however, that further evidence is needed on the point.

It is obvious, too, that so far as free nitrogen may be fixed by microbes within the soil independently of connection with a higher plant, the resulting nitrogenous compounds should, directly or indirectly, be available to plants generally, whether leguminous or non-leguminous.

On this point it may be remarked that about thirty years ago Boussingault concluded, from the results of vegetation experiments made in 1858 and 1859, in mixtures of rich soil and sand, that free nitrogen had been fixed within the soil by the agency of mycodermic vegetation, and that the nitrogenous products which remained within it were largely in the form of organic detritus. Subsequently, however, he considered that there was not satisfactory evidence that free nitrogen is fixed within the soil under the influence of the development of lower organisms. It is of interest to observe, however, that those of his results in 1858 and 1859 which showed any material gain of nitrogen, either in the vegetable matter grown or in the soil, were obtained with *Leguminosæ*; and that, in the case in which there was the greatest gain in the plants themselves, he records that there were numerous tubercles

on their roots. In one other case, in which however only sand was used as soil, and the gain in the plant was but small, he also observed tubercles on the roots. In the other cases of gain no mention is made of tubercles, and it may be that the roots were not so examined as to determine whether they existed or not. It is, at any rate, very significant, when viewed in the light of recently acquired knowledge, that in all the cases of gain the plants grown were of the leguminous family, and that in some of them nodules were observed on the roots.

On the other hand, Berthelot considers that he has experimentally proved the fixation of free nitrogen by the agency of microbes within the soil, both in the absence of higher vegetation, and also coincidently with the growth of *non*-leguminous plants. He further considers that such fixation takes place to an extent which would be an important source of nitrogen to our crops. Whether or not this experimental result be eventually confirmed, it may safely be said, that neither experience in practical agriculture, nor the nitrogen statistics of soils and crops, points to the conclusion that our *non*-leguminous crops do acquire nitrogen rendered available by the fixation of free nitrogen under the agency of microbes within the soil independently of leguminous growth, or at any rate that they do so in any material degree.

In 1888, however, Berthelot made numerous experiments with Leguminosæ, and in many of them he found very large gains of nitrogen; indeed a much higher range of gain than in his other experiments. That there should be large gain under such conditions is quite consistent with the results which have been recorded of the experiments made at Rothamsted in 1888 and since, with Leguminosæ; and, like them, Berthelot's results contribute to the confirmation of those of Hellriegel and Wilfarth. Further, these results of Berthelot, like those obtained at Rothamsted and by others with leguminous plants, are consistent with well established facts of agricultural production, and with the nitrogen statistics of soils and crops, and serve, with them, to aid the solution of long recognised problems in connection with the growth of Leguminous crops.

But, whether or not it may eventually be established that nitrogen is fixed by microbes within the soil independently of leguminous growth, there is evidence that in soils and subsoils containing organic nitrogen, lower organisms may serve the higher plants, by taking up, or attacking and bringing into a more readily available condition, combined nitrogen not otherwise, or only very slowly, available for the higher plants. For example, it is probable that Fungi generally, derive nitrogen from organic nitrogen; and in the case of those of Fairy Rings there can be little doubt that they take up from the soil organic nitrogen which is not available to the meadow plants, and that, on their decay, their nitrogen becomes available to the associated herbage. Then in the case of the fungus mantle observed by Frank on the roots of certain trees, it may be supposed that the fungus takes up organic nitrogen, and so becomes the medium of the supply of the

soil nitrogen to the plant. More pertinent still is the action of the nitrifying organisms in rendering the organic nitrogen of the soil and subsoil available to the higher plants. It may well be supposed, therefore, that there may be other cases in which lower organisms may serve the higher, by bringing into a more available condition the combined nitrogen already existing, but in a comparatively inert state, in soils and subsoils.

As to the undoubted fixation of free nitrogen in the growth of leguminous crops under the influence of suitable microbe infection, and of the development of nodules on the roots of the plants, the alternative explanations seem to be :—

1. That the plant is enabled, under the conditions of the symbiosis, to fix the free nitrogen of the atmosphere by its leaves.

2. That the organisms become distributed within the soil and there fix free nitrogen ; the resulting nitrogenous compounds becoming available as a source of nitrogen to the roots of the higher plant.

3. That free nitrogen is fixed in the course of the development of the organisms within the nodules, and that the resulting nitrogenous compounds are absorbed and utilised by the host.

It seems to me that the balance of the evidence at present at command is much in favour of the third mode of explanation.

It must be admitted, however, that more evidence is needed as to the mode of life of the parasite, especially having regard to the surrounding media. The subject, in various aspects, is being further investigated at Rothamsted. Experiments have been made or are in progress to determine the amount of gain, if any, under the influence of soil-extract seeding, in the case of—peas, beans, vetches, lupins, white clover, red clover, sainfoin, and lucerne. It is obvious, however, that in the case of experiments conducted with a view to the analysis of the final products of growth, no examination of the roots of the plants, and of the nodule-formation on them, can take place until the conclusion of the experiment. Accordingly, a series of experiments has this year been arranged, in such manner as to admit of the careful examination of the roots at successive periods of the growth of the plants. The same eight descriptions of leguminous plant as above enumerated are thus under experiment. Each is grown in a comparatively pure, but unwashed and unsterilised sand, with soil-extract added ; and also in a mixture of rich garden soil and sand. It is obvious that, under such conditions, any difference in the character of the development of the roots, or of the nodules on them, on the one hand in an almost nitrogen-free but duly infected soil, and on the other in one rich in compounds of nitrogen, can advantageously be studied.

OF WHAT IMPORTANCE TO AGRICULTURE IS THE NEWLY-ESTABLISHED SOURCE OF NITROGEN TO LEGUMINOUS CROPS ?

The question yet remains :—What is the practical importance of this newly-established source of nitrogen to the Leguminosæ, considered

in its bearing on the known facts of Agricultural production, and especially on the question of the sources of the nitrogen, not only of Leguminous crops themselves, but of crops generally? Unfortunately, as in the matter of the explanation of the action by which the nitrogen is fixed, there is much yet to learn, before a satisfactory answer can be given. Still it may be well to report progress.

In our recent paper in the "*Philosophical Transactions*" (Vol. 180 B), we said that whilst experience, whether practical or experimental, did not point to an unsolved problem in the matter of the sources of the nitrogen of the agricultural plants of other families, it was quite otherwise so far as those of the Leguminosæ were concerned. It is true that both agricultural investigation, and direct vegetation experiment, have clearly shown that Leguminosæ do take up much soil-nitrogen, and, at any rate in great part, as nitrate. But it was admitted that, in some cases, there was no evidence to justify the conclusion that the whole of the nitrogen had been so derived; and hence, that some other explanation of the large amounts assimilated was needed.

It has been seen that the balance of experimental evidence is against the supposition that the higher plants growing under sterilised conditions can assimilate free-nitrogen. But, it is now established that, at any rate in the case of some leguminous plants, they may acquire nitrogen coincidently with the development on their roots of tubercular bodies with bacteroid contents; and the evidence points to the conclusion, that it is the lower organisms, and not the higher plants, that fix free nitrogen.

It has been stated that the characteristic nodules have been found on the roots of various Leguminosæ growing among the mixed herbage of grass-land, and also on those of others growing on arable land, in the ordinary course of agriculture. It has been suggested, that when such plants are growing in soil and subsoil containing an abundance of combined nitrogen, lower organisms may serve the higher, at any rate in part, by bringing the already combined nitrogen of the soil and subsoil into a more readily available condition. But, so far as free nitrogen may be brought into combination, the question arises—under what conditions will this action come the more or the less into play?

As bearing upon this subject, it may be stated that, in experiments with beans, Professor Vines found that the formation of nodules on the roots was very much reduced, if not only accidental, when the plants were liberally supplied with nitrate. Again, in some of the experiments at Rothamsted which have been described, there was a less development of nodules when the soil contained an abundance of combined nitrogen. On the other hand, some observers have concluded that the development of the nodules is the greater, the greater the supply of nitrogenous compounds at the disposal of the roots; and, in some of the experiments at Rothamsted, this has undoubtedly been the case. It is admitted, however, that further evidence is required on the point, and it is believed that the experiments now in

progress, to which reference has been made, will afford some definite information on the subject.

It would seem not improbable that different Leguminosæ may behave differently in this respect. Should this prove to be the case, and supposing it be established that fixation of free nitrogen is always a coincident of the nodule development, it would be concluded that when nodules develop abundantly on the roots of Leguminous plants growing in soil rich in readily available combined nitrogen, the nitrogen assimilation will be largely due both to soil nitrogen and to fixation. On the other hand, it is clear, as in the case of the experiments with yellow lupins growing in nitrogen-free but duly-infected sand, for example, that the nitrogen assimilation may be very large in the absence of any initial soil supply beyond that in the seed sown. Obviously in such a case the assimilation will be almost entirely due to fixation.

Should the results of further investigation and observation confirm the indication that on the roots of some Leguminosæ nodules develop the more, and that there is coincidently a greater gain of nitrogen due to fixation, the richer the soil in available combined nitrogen, whilst with others it is not so, or that there is at any rate great gain without such soil supply, it is obvious that the proportion in which a leguminous crop will derive its nitrogen, on the one hand from soil supplies of combined nitrogen, and on the other from fixation under the influence of the symbiotic life, may be very different, according to the peculiarities of the particular description of plant, and to the characters of the soil as to available supply of combined nitrogen, mechanical condition, and due infection.

SUMMARY AND CONCLUSION.

There is no evidence that the leguminous plant itself assimilates free nitrogen. The evidence at present at command, is in favour of the supposition that the observed gain is due to the fixation of nitrogen in the development of the lower organisms in the root-nodules, and that the nitrogenous compounds produced are taken up and utilised by the leguminous plant. Further, the development of the supposed nitrogen fixing bodies is obviously dependent on due infection with organisms essential to the setting up of the symbiotic life in the particular leguminous plant to be grown.

It seems probable that, in the growth in practical agriculture of leguminous crops, such as clover, vetches, peas, beans, lucerne, &c., at any rate some, and in some cases a considerable proportion, of the large amount of nitrogen which they contain, and of the large amount which they frequently leave as nitrogenous residue in the soil for future crops, may be due to free nitrogen so brought into combination by the agency of lower organisms.

It has yet to be determined, under what conditions a greater or less proportion of the total nitrogen of the crop will be derived—on the one

hand from nitrogen-compounds within the soil, and on the other from such fixation.

Incidentally the question suggests itself—how far the failure of red clover, or of other leguminous crops, may be due to the exhaustion of the organisms necessary for nodule development, and for the consequent fixation of free nitrogen, and how far to the exhaustion of combined nitrogen in an available condition, or of the necessary mineral constituents, within the range of the roots?

Assuming it to be established that a considerable proportion of the nitrogen of our leguminous crops is due to fixation under the conditions supposed, it is obvious that such a fact will not only serve to explain the source of the hitherto unaccounted for amount of the nitrogen of those crops themselves, but it will also aid the explanation of the source of the increased amount of nitrogen which other crops acquire, when they are grown in association, or in alternation, with Leguminosæ. Lastly, it will help to explain the source of part of the accumulated combined nitrogen within our soils, and the comparatively slow exhaustion of their stores of it, by cropping, drainage, and in other ways.

OBSERVATIONS

ON

RAINFALL, PERCOLATION,

AND

EVAPORATION;

WITH RESULTS OBTAINED AT ROTHAMSTED, OVER TWENTY HARVEST YEARS, 1870–1 TO 1889–90 INCLUSIVE.

BY

DR. J. H. GILBERT, F.R.S., &c.

By permission of the Council.

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OBSERVATIONS

ON

RAINFALL, PERCOLATION,

AND

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Dr. J. H. GILBERT remarked that as Mr. Harrison had referred to the results obtained by Sir John Lawes and himself, and had founded important estimates upon them, they thought it might be of interest to provide further data than had been already published, and they had accordingly prepared the Tables now exhibited. Mr. Harrison had referred to ten years of percolation experiments; but in the Tables they had given the results of twenty years up to last autumn. The first Table showed, for each of the twenty years, the amount of rain in inches, the percolation in inches, through 20, 40, and 60 inches of soil, and the complementary amounts, which represented evaporation; also the averages for the twenty years. In the second Table would be found the average for each month of the year over the twenty years. The results were given for harvest-years, from September 1st to August 31st. Not only was that method of computation of interest to them as agriculturists, but he thought it ought to be adopted by those who studied the question of drainage from other points of view. Thus, the second Table showed that the average minimum drainage was in August; and that in September the amount began to increase. If the civil year were taken it would be found that the end of December cut the drainage in the middle of the period of

[1] The Observations were made at the meeting held on March 10, 1891, in the course of the discussion of Mr. J. Thornhill Harrison's paper, "On the Subterranean Water in the Chalk Formation of the Upper Thames, and its Relation to the Supply of London."

greatest activity; whilst marked decline commenced with March, not April, the point of civil year division. For other purposes, therefore, as well as those of agriculture, the harvest-year was more appropriate than the civil year. But perhaps he ought to say a word as to the observations of Mr. Symons, who had called in question, more or less, the validity of the whole thing. If, as he suggested, there was material drainage between the soil and the walls, the results were of course of very little value; but Dr. Gilbert thought they might be satisfied that the soil would very soon settle sufficiently close to the wall to prevent any such abnormal action.

Taking the average of the twenty years, the minimum drainage was in August, but the details for each individual year showed that it was frequently before August, and very rarely after it; and the recommencement of the drainage was very seldom in August, though with very heavy rain they might have much drainage, and it was not often later than September. If the drainage-beds had been covered with vegetation, the average minimum drainage would be earlier than August, and the recommencement would begin later than September. He might be permitted to call attention to one or two of the main results. The first ten years, with an average of about 30 inches of rain, gave 13·21, 13·94, and 12·17 inches, according to the depth of soil, viz., 20, 40, and 60 inches. With a rather less rainfall during the second ten years they had 15·54, 16·38, and 15·05 inches of drainage. That was, with a rather less rainfall there was a larger amount of drainage. There was less through the 60 inches than through the 20 inches of soil. One vitiating element in experiments of this kind obviously was that they were obliged to cut off the drainage at a particular point, so that there was no possibility of a return upwards. If, however, they compared the drainage through the 60 inches with that through the 20 inches, they would find that there was a little less through the greater depth, which was evidence that there had been a return upwards below the point at which it was cut off in the 20-inch gauge; but the fact of its being so little less, he thought, showed that the conditions were not very wide of what they might be under ordinary circumstances. Then as to the larger amount of drainage through the 40-inch gauge, it was found that the Rothamsted subsoil was exceedingly variable, and they were able to judge from the composition of the water that passed through it that the subsoil in the 40-inch gauge was probably more gravelly, and therefore there was more percolation; there was, moreover, with more drainage, less nitric acid in it.

The advantage of having a greater number of years, and full details, was that they were able not only to get a better average, but to study the maxima and the minima, which were of the greatest importance, especially the latter, when they came to consider what was available over a series of years. It would be seen by the first Table, that in 1873–4, with a rainfall of something under 22 inches, the drainage was only 5·74, 5·40, and 3·94 inches. In 1879-80, with a rainfall also between 21 and 22 inches, the drainage was 6·89, 7·39, and 6·50; whereas, in 1878-9, with a rainfall of 41 inches, the drainage was 24·44, 26·03, and 24·38. In 1880-1, with a rainfall of 36·77 inches, the drainage was 22·38, 22·84, and 21·26 inches. Thus, within the harvest-year they might have little more than 5 inches of drainage, or as much as from 22 to 25 or 26 inches. Such results were of great importance to study when considering what would be available under any given circumstances.

The details further showed that although the rainfall obviously had a considerable influence upon it, the amount of drainage was by no means proportional to the rainfall, but depended to a great extent upon the distribution as well. Thus, to give a very obvious example, if they had a given amount of heavy rain during the growing period, there might be no drainage at all; whilst the same quantity during the winter, when there was no vegetation, and little evaporation, might give a very large proportion of drainage. The drainage was, in fact, materially affected by the distribution of the rain, and the drainage and evaporation were, of course, complementary to one another. The Table showed that taking the difference between rainfall and percolation to represent evaporation, they had in two years only 12 inches of evaporation, and in several between 19 and 20 inches; so that there was a great difference in that respect also. According to the average of twenty years, with rather heavy soil, free from vegetation, it might be said that the drain-gauges gave about 14 inches. It was difficult to estimate exactly what deduction should be made for vegetation. A large proportion of any area that they had to consider was covered with vegetation. Sir John Lawes and himself had considered that the minimum amount would average 2 inches, as in the case of downs or waste lands, where there was very little vegetation; whereas with a heavy grain-crop, or good mangel crop, there might be an evaporation of 7 inches or more. Taking the average of a large area around London, partly covered with vegetation and partly bare, over a number of seasons, they thought that between 3 and 4 inches should be deducted from the 14 inches of percolation, so leaving 10

or 11 inches. Supposing the average rainfall to be about 30 inches for the twenty years, that left about 19 or 20 inches for evaporation, both by the soil and by vegetation. This agreed very fairly with the results of Dr. Evans and others. Further, in reference to the interpretation of the figures which he had given, it should be observed that the estimated rainfall of the Chalk district was about 27 inches. The rainfall over the twenty years at Rothamsted was, however, 30 inches by the large one-thousandth of an acre gauge, but only 29 inches by the 5-inch gauge. The large gauge recorded a great many small deposits which could not be measured by a small one; and there were also some other irregularities. But if they used the same kind of gauge as that by which the observations of others were mostly made, the ordinary 5-inch gauge, the result would be 29 inches, whereas the estimate for the whole district was only between 26 and 27 inches. Hence the Rothamsted results to which he had referred probably indicated a rather exaggerated amount of drainage for the whole district.

A point to which he wished particularly to call attention was, that the details—the minima as well as the averages—should be studied, if they were to form any trustworthy conclusions from such results. He admitted with Mr. Symons, that there was something artificial in that mode of estimating the drainage of a district, but he knew of no better. He had received a memorandum from Sir John Lawes, calling attention to two or three particular points. The first referred to the fact that, within a mile to the eastward of the gauges, there had undoubtedly been a river before his time, and to the westward there was the Ver, which had gone down immensely during his lifetime, and had often been dry. Then again, the wells had frequently to be lowered, and the water-supply was at any rate lessening, and whether the scheme now in question would or would not affect the waters to the north of London, it was of the greatest importance that nothing should be done to reduce them; for there could be no doubt that they would want all they could get. Sir John Lawes agreed with Mr. Harrison in thinking it extremely desirable that they should have better gaugings of the flow and discharges of the rivers in the chalk district north of London.

EXPERIMENTS ON RAINFALL AND DRAINAGE AT ROTHAMSTED.

TABLE A.—Summary of results, 20 years.

—	Rainfall.		Drainage through soil (uncropped).			Difference,[1] approximately = evaporation.		
	5-Inch Funnel Gauge.	$\frac{1}{1000}$th Acre Gauge.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.
Harvest years, Sept. 1 to Aug. 31.								
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
1870–1	26·49	27·55	9·64	9·42	5·81	17·91	18·13	21·74
1871–2	27·83	29·02	9·69	9·39	8·24	19·33	19·63	20·78
1872–3	28·99	30·66	14·35	13·67	12·03	16·31	16·99	18·63
1873–4	20·29	21·69	5·74	5·40	3·94	15·95	16·29	17·75
1874–5	27·87	31·61	12·25	12·72	10·30	19·36	18·89	21·31
1875–6	28·83	31·98	14·75	16·87	15·46	17·23	15·11	16·52
1876–7	37·73	39·28	19·63	22·07	20·20	19·65	17·21	19·08
1877–8	32·11	32·65	14·72	16·44	14·84	17·93	16·21	17·81
1878–9	40·17	41·05	24·44	26·03	24·38	16·61	15·02	16·67
1879–80	20·88	21·36	6·89	7·39	6·50	14·47	13·97	14·86
1880–1	35·85	36·77	22·38	22·84	21·26	14·39	13·93	15·51
1881–2	31·66	32·31	15·31	16·08	14·32	16·50	16·23	17·99
1882–3	33·69	34·71	20·82	21·72	19·72	13·89	12·99	14·99
1883–4	25·29	25·77	11·86	12·00	11·21	13·91	13·77	14·56
1884–5	25·90	26·78	14·82	15·14	13·98	11·96	11·64	12·80
1885–6	29·46	31·02	17·37	18·41	16·57	13·65	12·61	14·45
1886–7	22·63	23·61	10·64	12·58	11·72	12·97	11·03	11·89
1887–8	29·11	30·50	13·96	15·58	14·67	16·54	14·92	15·83
1888–9	28·79	30·09	14·64	15·82	14·33	15·45	14·27	15·76
1889–90	26·73	27·43	13·16	13·60	12·74	14·27	13·83	14·69
Averages . .	29·02	30·29	14·38	15·16	13·61	15·91	15·13	16·68

[1] Calculated on the rainfall shown by the $\frac{1}{1000}$th acre gauge.

EXPERIMENTS ON RAINFALL AND DRAINAGE AT ROTHAMSTED.

—	Rainfall.		Drainage through soil (uncropped).			Difference,[1] approximately = evaporation.		
	5-Inch Funnel Gauge.	$\frac{1}{1000}$th Acre Gauge.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.
TABLE B.—Averages for each month, 20 Harvest-years.								
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
September . . .	2·74	2·86	0·96	0·85	0·75	1·90	2·01	2·11
October	3·07	3·20	1·78	1·74	1·50	1·42	1·46	1·70
November . . .	2·92	3·03	2·24	2·30	2·05	0·79	0·73	0·98
December . . .	2·31	2·42	1·90	2·02	1·81	0·52	0·40	0·61
January	2·34	2·51	1·96	2·25	2·06	0·55	0·26	0·45
February . . .	1·92	2·04	1·44	1·59	1·44	0·60	0·45	0·60
March	1·61	1·74	0·80	0·95	0·86	0·94	0·79	0·88
April	2·12	2·21	0·67	0·74	0·68	1·54	1·47	1·53
May	2·22	2·28	0·60	0·68	0·59	1·68	1·60	1·69
June	2·45	2·52	0·63	0·64	0·60	1·89	1·88	1·92
July	2·96	3·03	0·84	0·85	0·77	2·19	2·18	2·26
August	2·36	2·45	0·56	0·55	0·50	1·89	1·90	1·95
Total . . .	29·02	30·29	14·38	15·16	13·61	15·91	15·13	16·68
TABLE C.—General Summary, average actual results per annum.								
10 years, 1870–1 to 1879–80 . . .	29·12	30·68	13·21	13·94	12·17	17·47	16·74	18·51
10 years, 1880–1 to 1889–90 . . .	28·91	29·91	15·54	16·38	15·05	14·37	13·53	14·86
20 years, 1870–1 to 1889–90 . . .	29·02	30·29	14·38	15·16	13·61	15·91	15·13	16·68
TABLE D.—General Summary, average per cent. drainage and evaporation to rainfall.[1]								
10 years, 1870–1 to 1879–80 . . .	..	..	43·1	45·4	39·7	56·9	54·6	60·3
10 years, 1880–1 to 1889–90 . . .	..	..	52·0	54·8	50·3	48·0	45·2	49·7
20 years, 1870–1 to 1889–90 . . .	..	..	47·5	50·0	44·9	52·5	50·0	55·1

[1] Calculated on the rainfall shown by the $\frac{1}{1000}$th acre gauge.

EXPERIMENTS ON RAINFALL AND DRAINAGE AT ROTHAMSTED.

Monthly Record for each Harvest-year, Sept. 1 to Aug. 31.

	Rainfall.		Drainage through Soil (uncropped).			Difference,[1] approximately = evaporation.		
	5-Inch Funnel Gauge.	$\frac{1}{1000}$th Acre Gauge.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.
1870–1.								
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
September . . .	2·11	2·31	0·22	0·06	0·02	2·09	2·25	2·29
October	3·87	4·13	1·07	0·45	0·18	3·06	3·68	3·95
November . . .	1·24	1·40	1·84	1·42	0·71	−0·44	−0·02	0·69
December . . .	2·53	2·65	2·10	1·95	1·07	0·55	0·70	1·58
January	1·40	1·45	0·25	1·12	0·72	1·20	0·33	0·73
February . . .	1·64	1·63	0·91	1·13	0·71	0·72	0·50	0·92
March	1·38	1·50	0·34	0·43	0·23	1·16	1·07	1·27
April	2·82	2·89	0·81	0·80	0·63	2·08	2·09	2·26
May	0·94	0·96	..	0·05	0·04	0·96	0·91	0·92
June	3·89	3·87	1·29	1·15	0·90	2·58	2·72	2·97
July	3·99	3·99	0·81	0·85	0·60	3·18	3·14	3·39
August	0·68	0·77	..	0·01	..	0·77	0·76	0·77
Total . . .	26·49	27·55	9·64	9·42	5·81	17·91	18·13	21·74
1871–2.								
September . . .	4·60	4·74	1·82	1·43	1·08	2·92	3·31	3·66
October	0·94	1·12	0·12	0·24	0·23	1·00	0·88	0·89
November . . .	0·60	0·66	0·07	0·14	0·35	0·59	0·52	0·31
December . . .	1·28	1·43	0·82	0·76	0·48	0·61	0·67	0·95
January	4·51	4·67	3·64	3·55	3·13	1·03	1·12	1·54
February . . .	1·36	1·52	0·64	0·77	0·58	0·88	0·75	0·94
March	1·84	2·12	0·92	0·82	0·83	1·20	1·30	1·29
April	1·56	1·61	0·09	0·16	0·13	1·52	1·45	1·48
May	2·88	2·90	0·77	0·75	0·63	2·13	2·15	2·27
June	3·25	3·25	0·77	0·74	0·76	2·48	2·51	2·49
July	2·73	2·72	0·01	0·01	0·01	2·71	2·71	2·71
August	2·28	2·28	0·02	0·02	0·03	2·26	2·26	2·25
Total . . .	27·83	29·02	9·69	9·39	8·24	19·33	19·63	20·78

[1] Calculated on the rainfall shown by the $\frac{1}{1000}$th acre gauge. When the drainage exceeds the rainfall the difference is entered as a minus quantity.

EXPERIMENTS ON RAINFALL AND DRAINAGE AT ROTHAMSTED.

Monthly Record for each Harvest-year, Sept. 1 to Aug. 31.

	Rainfall.		Drainage through Soil (uncropped).			Difference,[1] approximately = evaporation.		
	5-Inch Funnel Gauge.	$\frac{1}{1000}$th Acre Gauge.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.
1872–3.								
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
September . . .	1·28	1·37	0·01	0·02	0·01	1·36	1·35	1·36
October	4·59	4·67	3·13	2·68	2·10	1·54	1·99	2·57
November . . .	3·90	4·03	2·85	2·80	2·44	1·18	1·23	1·59
December . . .	3·97	4·16	3·38	3·40	3·04	0·78	0·76	1·12
January	3·53	3·74	2·77	2·73	2·71	0·97	1·01	1·03
February . . .	1·13	1·34	0·71	0·54	0·55	0·63	0·80	0·79
March	1·90	2·05	0·88	1·02	0·80	1·17	1·03	1·25
April	0·54	0·64	..	0·01	0·01	0·64	0·63	0·63
May	1·74	1·87	..	..	..	1·87	1·87	1·87
June	1·66	1·76	..	..	..	1·76	1·76	1·76
July	2·31	2·39	0·62	0·47	0·37	1·77	1·92	2·02
August	2·44	2·64	..	..	..	2·64	2·64	2·64
Total . . .	28 99	30·66	14·35	13·67	12·03	16·31	16·99	18·63
1873–4.								
September . . .	2·22	2·38	0·70	0·38	0·20	1·68	2·00	2·18
October	2·61	2·82	0·99	0·83	0·29	1·83	1·99	2·53
November . . .	1·82	1·99	1·08	1·11	0·86	0·91	0·88	1·13
December . . .	0·59	0·71	0·15	0·11	0·04	0·56	0·60	0·67
January	1·78	1·93	1·22	1·35	1·21	0·71	0·58	0·72
February . . .	1·62	1·73	0·85	0·84	0·73	0·88	0·89	1·00
March	0·50	0·65	0 01	0·04	0·03	0·64	0·61	0·62
April.	2·00	2·14	0·32	0·29	0·25	1·82	1·85	1·89
May	1·14	1·19	..	..	..	1·19	1·19	1·19
June	1·53	1·59	..	..	..	1·59	1·59	1·59
July	2·82	2·81	0·42	0·45	0·33	2·39	2·36	2·48
August	1·66	1·75	..	..	..	1·75	1·75	1·75
Total . . .	20·29	21·69	5·74	5·40	3·94	15·95	16·29	17·75

[1] Calculated on the rainfall shown by the $\frac{1}{1000}$th acre gauge.

EXPERIMENTS ON RAINFALL AND DRAINAGE AT ROTHAMSTED.

Monthly Record for each Harvest-year, Sept. 1 to Aug. 31.

	Rainfall.		Drainage through Soil (uncropped).			Difference,[1] approximately = evaporation.		
	5-Inch Funnel Gauge.	$\frac{1}{1000}$th Acre Gauge.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.
1874–5.								
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
September . . .	3·48	3·62	0·63	0·25	0·21	2·99	3·37	3·41
October	3·05	3·22	1·52	1·26	1·02	1·70	1·96	2·20
November . . .	2·10	2·34	1·21	1·04	0·69	1·13	1·30	1·65
December . . .	1·61	1·80	1·16	1·34	1·04	0·64	0·46	0·76
January	3·01	3·99	2·87	3·39	2·62	1·12	0·60	1·37
February . . .	0·77	1·18	0·34	0·44	0·38	0·84	0·74	0·80
March	0·75	0·87	0·50	0·57	0·46	0·37	0·30	0·41
April	1·38	1·56	0·09	0·11	0·06	1·47	1·45	1·50
May	2·52	2·74	0·29	0·37	0·30	2·45	2·37	2·44
June	3·15	3·53	0·35	0·26	0·14	3·18	3·27	3·39
July	5·06	5·66	3·29	3·66	3·35	2·37	2·00	2·31
August	0·99	1·10	..	0·03	0·03	1·10	1·07	1·07
Total . . .	27·87	31·61	12·25	12·72	10·30	19·36	18·89	21·31
1875–6.								
September . . .	2·46	2·80	0·89	0·83	0·71	1·91	1·97	2·09
October	5·13	5·90	3·72	3·95	3·55	2·18	1·95	2·35
November . . .	3·95	4·43	3·24	3·54	3·26	1·19	0·89	1·17
December . . .	0·90	1·19	0·78	1·01	0·97	0·41	0·18	0·22
January	1·59	1·81	1·46	1·76	1·67	0·35	0·05	0·14
February . . .	2·79	3·05	1·87	2·20	1·94	1·18	0·85	1·11
March	2·42	2·90	1·28	1·74	1·58	1·62	1·16	1·32
April	3·24	3·33	1·36	1·66	1·72	1·97	1·67	1·61
May	0·76	0·78	..	0·04	0·03	0·78	0·74	0·75
June	1·33	1·35	..	..	..	1·35	1·35	1·35
July	1·43	1·46	..	..	..	1·46	1·46	1·46
August	2·83	2·98	0·15	0·14	0·03	2·83	2·84	2·95
Total . . .	28·83	31·98	14·75	16·87	15·46	17·23	15·11	16·52

[1] Calculated on the rainfall shown by the $\frac{1}{1000}$th acre gauge.

EXPERIMENTS ON RAINFALL AND DRAINAGE AT ROTHAMSTED.

Monthly Record for each Harvest-year, Sept. 1 to Aug. 31.

	Rainfall.		Drainage through Soil (uncropped).			Difference,[1] approximately = evaporation.		
	5-inch Funnel Gauge.	$\frac{1}{1000}$th Acre Gauge.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.
1876–7.								
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
September . . .	4·59	5·02	2·30	2·24	2·04	2·72	2·78	2·98
October	1·37	1·52	0·82	1·10	0·96	0·70	0·42	0·56
November . . .	4·00	4·20	2·89	2·99	2·66	1·31	1·21	1·54
December . . .	5·80	6·00	5·21	5·74	5·25	0·79	0·26	0·75
January	4·82	4·99	3·79	4·41	4·11	1·20	0·58	0·88
February . . .	1·98	2·10	0·87	1·19	1·23	1·23	0·91	0·87
March	2·52	2·55	1·01	1·25	1·10	1·54	1·30	1·45
April.	2·68	2·76	1·33	1·61	1·49	1·43	1·15	1·27
May	2·79	2·82	0·44	0·55	0·51	2·38	2·27	2·31
June	1·39	1·44	0·03	0·09	0·10	1·41	1·35	1·34
July	3·23	3·28	0·56	0·51	0·44	2·72	2·77	2·84
August	2·56	2·60	0·38	0·39	0·31	2·22	2·21	2·29
Total . . .	37·73	39·28	19·63	22·07	20·20	19·65	17·21	19·08
1877–8.								
September . . .	1·53	1·53	0·21	0·26	0·21	1·32	1·27	1·32
October	1·90	1·95	0·58	0·51	0·39	1·37	1·44	1·56
November . . .	5·15	5·16	4·03	4·20	3·82	1·13	0·96	1·34
December . . .	2·28	2·28	1·74	1·98	1·75	0·54	0·30	0·53
January	1·73	1·75	1·10	1·36	1·20	0·65	0·39	0·55
February . . .	1·77	1·80	1·01	1·20	1·13	0·79	0·60	0·67
March	0·88	0·98	0·27	0·50	0·46	0·71	0·48	0·52
April.	4·01	4·09	2·35	2·52	2·43	1·74	1·57	1·66
May	4·89	4·97	1·48	1·85	1·50	3·49	3·12	3·47
June	2·46	2·51	0·61	0·86	0·76	1·90	1·65	1·75
July	0·64	0·65	0·01	0·03	0·06	0·64	0·62	0·59
August	4·87	4·98	1·33	1·17	1·13	3·65	3·81	3·85
Total . . .	32·11	32·65	14·72	16·44	14·84	17·93	16·21	17·81

[1] Calculated on the rainfall shown by the $\frac{1}{1000}$th acre gauge.

EXPERIMENTS ON RAINFALL AND DRAINAGE AT ROTHAMSTED.

Monthly Record for each Harvest-year, Sept. 1 to Aug. 31.

	Rainfall.		Drainage through Soil (uncropped).			Difference,[1] approximately = evaporation.		
	5-Inch Funnel Gauge.	$\frac{1}{1000}$th Acre Gauge.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.
1878–9.								
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
September . . .	1·41	1·46	0·07	0·12	0·11	1·39	1·34	1·35
October	2·99	2·99	1·37	1·39	1·10	1·62	1·60	1·89
November . . .	4·73	4·55	3·77	4·07	3·66	0·78	0·48	0·89
December . . .	1·57	1·60	1·11	1·37	1·54	0·49	0·23	0·06
January	2·46	2·85	2·47	2·65	2·47	0·38	0·20	0·38
February . . .	3·73	3·80	4·44	4·44	4·22	−0·64	−0·64	−0·42
March	1·09	1·18	0·14	0·28	0·26	1·04	0·90	0·92
April.	2·61	2·79	1·27	1·51	1·38	1·52	1·28	1·41
May	3·45	3·48	1·22	1·39	1·30	2·26	2·09	2·18
June	5·49	5·55	2·15	2·24	2·18	3·40	3·31	3·37
July	4·17	4·24	1·83	1·97	1·81	2·41	2·27	2·43
August	6·47	6·56	4·60	4·60	4·35	1·96	1·96	2·21
Total . . .	40·17	41·05	24·44	26·03	24·38	16·61	15·02	16·67
1879–80.								
September . . .	3·07	3·13	1·11	1·00	0·92	2·02	2·13	2·21
October	0·76	0·82	0·22	0·42	0·43	0·60	0·40	0·39
November . . .	0·71	0·81	0·20	0·12	0·10	0·61	0·69	0·71
December . . .	0·78	0·82	0·41	0·49	0·44	0·41	0·33	0·38
January	0·55	0·55	0·48	0·61	0·46	0·07	−0·06	0·09
February . . .	2·88	2·90	2·36	2·59	2·30	0·54	0·31	0·60
March	1·10	1·13	0·04	0·09	0·09	1·09	1·04	1·04
April.	2·14	2·16	0·49	0·53	0·43	1·67	1·63	1·73
May	0·71	0·74	..	0·02	0·03	0·74	0·72	0·71
June	1·94	1·97	0·01	0·01	0·02	1·96	1·96	1·95
July	5·22	5·26	1·35	1·23	1·06	3·91	4·03	4·20
August	1·02	1·07	0·22	0·28	0·22	0·85	0·79	0·85
Total . . .	20·88	21·36	6·89	7·39	6·50	14·47	13·97	14·86

[1] Calculated on the rainfall shown by the $\frac{1}{1000}$th acre gauge. When the drainage exceeds the rainfall the difference is entered as a minus quantity.

EXPERIMENTS ON RAINFALL AND DRAINAGE AT ROTHAMSTED.

Monthly Record for each Harvest-year, Sept. 1 to Aug. 31.

	Rainfall.			Drainage through Soil (uncropped).			Difference,[1] approximately = evaporation.		
	8-Inch Funnel Gauge.	5 Inch Funnel Gauge.	$\frac{1}{1000}$th Acre Gauge.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.
1880–1.									
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
September .	..	5·69	5·86	3·96	3·93	3·78	1·90	1·93	2·08
October . .	..	5·88	5·94	4·47	4·45	4·07	1·47	1·49	1·87
November .	..	2·87	2·92	2·25	2·39	2·14	0·67	0·53	0·78
December .	..	3·45	3·47	2·82	2·85	2·68	0·65	0·62	0·79
January . .	1·07	1·12	1·14	1·01	1·12	1·32	0·13	0:02	–0·18
February .	3·35	3·33	3·70	3·43	3·71	3·29	0·27	–0·01	0·41
March . .	1·99	2·10	2·15	1·66	1·78	1·65	0·49	0:37	0·50
April. . .	0·92	0·97	1·00	..	0·01	0·03	1·00	0:99	0·97
May . . .	1·28	1·39	1·38	..	0·01	0·04	1·38	1:37	1·34
June . . .	1·53	1·62	1·63	0·01	0·02	0·04	1·62	1:61	1·59
July . . .	1·67	1·73	1·76	..	0·01	0·01	1·76	1:75	1·75
August . .	5·47	5·70	5·82	2·77	2·56	2·21	3·05	3:26	3·61
Total . .	17·28	35·85	36·77	22·38	22·84	21·26	14·39	13·93	15·51
1881–2.									
September .	2·01	2·09	2·17	0·81	0·81	0·70	1·36	1·36	1·47
October . .	2·84	2·93	3·05	1·76	1·73	1·53	1·29	1·32	1·52
November .	3·29	3·45	3·47	2·49	2·50	2·29	0·98	0·97	1·18
December .	4·16	4·33	4·38	3·95	4·04	3·65	0·43	0·34	0·73
January . .	1·42	1·55	1·57	1·24	1·38	1·23	0·33	0·19	0·34
February .	1·88	1·99	2·02	1·15	1·13	1·01	0·87	0·89	1·01
March . .	1·38	1·48	1·57	0·45	0·58	0·49	1·12	0·99	1·08
April. . .	3·71	3·82	3·92	1·87	1·77	1·57	2·05	2:15	2·35
May . . .	1·95	2·01	2·07	0·74	0·85	0·74	1·33	1:22	1·33
June . . .	3·79	3·90	3·93	1·25	1·15	0·99	2·68	2:78	2·94
July . . .	1·95	2·05	2·09	0·10	0·12	0·10	1·99	1:97	1·99
August . .	1·97	2·06	2·07	..	0·02	0·02	2·07	2:05	2·05
Total . .	30·35	31·66	32·31	15·81	16·08	14·32	16·50	16·23	17·99

[1] Calculated on the rainfall shown by the $\frac{1}{1000}$th acre gauge. When the drainage exceeds the rainfall, the difference is entered as a minus quantity.

EXPERIMENTS ON RAINFALL AND DRAINAGE AT ROTHAMSTED.

Monthly Record for each Harvest-year, Sept. 1 to Aug. 31.

	Rainfall.			Drainage through Soil (uncropped).			Difference,[1] approximately = evaporation.		
	8-Inch Funnel Gauge.	5-Inch Funnel Gauge.	$\frac{1}{1000}$th Acre Gauge.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.
1882–3.									
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
September .	2·15	2·21	2·29	0·71	0·57	0·40	1·58	1·72	1·89
October . .	6·39	6·46	6·52	5·46	5·55	5·10	1·06	0·97	1·42
November .	3·24	3·29	3·44	2·49	2·65	2·41	0·95	0·79	1·03
December .	3·07	3·03	3·28	3·00	3·22	2·98	0·28	0·06	0·30
January . .	3·19	3·28	3·30	2·89	3·11	2·81	0·41	0·19	0·49
February .	4·18	4·28	4·34	3·76	4·01	3·70	0·58	0·33	0·64
March . .	0·75	0·76	0·89	0·02	0·06	0·09	0·87	0·83	0·80
April . .	1·40	1·43	1·48	0·28	0·26	0·22	1·20	1·22	1·26
May . . .	1·77	1·84	1·89	0·63	0·70	0·62	1·26	1·19	1·27
June . . .	2·10	2·17	2·23	0·13	0·11	0·09	2·10	2·12	2·14
July . . .	4·03	4·16	4·21	1·44	1·42	1·25	2·77	2·79	2·96
August . .	0·71	0·78	0·84	0·01	0·06	0·05	0·83	0·78	0·79
Total. .	32·98	33·69	34·71	20·82	21·72	19·72	13·89	12·99	14·99
1883–4.									
September .	3·83	3·94	3·99	1·63	1·43	1·32	2·36	2·56	2·67
October . .	2·38	2·48	2·49	1·39	1·50	1·38	1·10	0·99	1·11
November .	3·35	3·46	3·52	2·77	2·71	2·47	0·75	0·81	1·05
December .	0·92	1·07	1·16	0·79	0·97	0·95	0·37	0·19	0·21
January . .	2·51	2·55	2·56	1·87	1·81	1·65	0·69	0·75	0·91
February .	1·31	1·38	1·42	0·72	0·92	0·86	0·70	0·50	0·56
March . .	1·59	1·64	1·66	1·13	1·18	1·10	0·53	0·48	0·56
April . .	1·69	1·74	1·79	0·24	0·18	0·19	1·55	1·61	1·60
May	0·58	0·61	0·64	0·04	0·09	0·11	0·60	0·55	0·53
June . . .	2·43	2·46	2·50	1·09	1·06	1·04	1·41	1·44	1·46
July . . .	2·34	2·40	2·44	0·16	0·10	0·10	2·28	2·34	2·34
August . .	1·51	1·56	1·60	0·03	0·05	0·04	1·57	1·55	1·56
Total .	24·44	25·29	25·77	11·86	12·00	11·21	13·91	13·77	14·56

[1] Calculated on the rainfall shown by the $\frac{1}{1000}$th acre gauge.

EXPERIMENTS ON RAINFALL AND DRAINAGE AT ROTHAMSTED.

Monthly Record for each Harvest-year, Sept. 1 to Aug. 31.

	Rainfall.			Drainage through Soil (uncropped).			Difference [1] approximately = evaporation.		
	8-inch Funnel Gauge.	5-inch Funnel Gauge.	$\frac{1}{1155}$th Acre Gauge.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.	20 Inches Deep.	40 Inches Deep	60 Inches Deep.
1884–5.									
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
September .	2·05	2·11	2·18	1·29	1·26	1·11	0·89	0·92	1·07
October . .	1·60	1·64	1·70	0·52	0·47	0·41	1·18	1·23	1·29
November .	1·86	1·87	2·05	0·72	0·69	0·61	1·53	1·36	1·44
December .	2·96	3·06	3·06	3·22	3·23	3·01	–0·16	–0·17	0·05
January . .	2·88	2·94	2·99	2·59	2·60	2·43	0·40	0·39	0·56
February .	2·73	2·84	2·85	2·43	2·60	2·45	0·42	0·25	0·40
March . .	1·30	1·19	1·46	0·63	0·71	0·67	0·83	0·75	0·79
April . .	2·76	2·81	2·88	1·04	1·05	0·92	1·84	1·83	1·96
May . . .	2·73	2·82	2·88	0·91	0·98	0·87	1·97	1·90	2·01
June . . .	2·68	2·71	2·76	1·46	1·52	1·46	1·30	1·24	1·30
July . . .	0·35	0·35	0·38	0·01	0·03	0·04	0·37	0·35	0·34
August . .	1·52	1·56	1·59	..	..	..	1·59	1·59	1·59
Total . .	25·42	25·90	26·78	14·82	15·14	13·98	11·96	11·64	12·80
1885–6.									
September .	4·19	4·31	4·39	1·55	1·42	1·25	2·84	2·97	3·14
October .	4·64	4·72	4·82	3·41	3·51	3·14	1·41	1·31	1·68
November .	3·65	3·73	3·77	3·41	3·59	3·31	0·36	0·18	0·46
December .	1·19	1·21	1·33	1·00	1·04	0·91	0·33	0·29	0·42
January . .	2·96	2·80	3·44	3·58	3·91	3·92	–0·14	–0·47	–0·48
February .	0·55	0·55	0·61	0·58	0·71	0·60	0·03	–0·10	0·01
March . .	1·42	1·44	1·59	0·83	0·93	0·69	0·76	0·66	0·90
April . .	1·83	1·88	1·96	0·59	0·73	0·58	1·37	1·23	1·38
May . . .	4·08	4·16	4·24	2·12	2·29	1·93	2·12	1·95	2·31
June . . .	1·14	1·15	1·23	0·08	0·12	0·10	1·15	1·11	1·13
July . . .	2·31	2·38	2·42	0·21	0·14	0·11	2·21	2·28	2·31
August . .	1·12	1·13	1·22	0·01	0·02	0·03	1·21	1·20	1·19
Total .	29·08	29·46	31·02	17·37	18·41	16·57	13·65	12·61	14·45

[1] Calculated on the rainfall shown by the $\frac{1}{1000}$th acre gauge. When the drainage exceeds the rainfall the difference is entered as a minus quantity.

EXPERIMENTS ON RAINFALL AND DRAINAGE AT ROTHAMSTED.

Monthly Record for each Harvest-year, Sept. 1 to Aug. 31.

	Rainfall.			Drainage through Soil (uncropped).			Difference,[1] approximately = evaporation.		
	8-Inch Funnel Gauge.	5-Inch Funnel Gauge.	$\frac{1}{1000}$th Acre Gauge.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.
1886–7.									
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
September .	1·38	1·43	1·51	0·01	..	0·01	1·50	1·51	1·50
October . .	3·77	3·91	3·94	2·16	1·99	1·74	1·78	1·95	2·20
November .	2·62	2·71	2·77	2·40	2·62	2·43	0·37	0·15	0·34
December .	4·12	4·17	4·21	2·46	2·58	2·36	1·75	1·63	1·85
January . .	2·22	2·20	2·39	2·32	3·83	3·78	0·07	−1·44	−1·39
February .	0·89	0·90	0·95	0·48	0·55	0·51	0·47	0·40	0·44
March . .	1·64	1·63	1·76	0·21	0·22	0·18	1·55	1·54	1·58
April . .	1·10	1·12	1·19	0·13	0·22	0·18	1·06	0·97	1·01
May . . .	2·22	2·25	2·35	0·04	0·06	0·07	2·31	2·29	2·28
June . . .	0·67	0 68	0·71	0·43	0·50	0·45	0·28	0·21	0·26
July . . .	0·71	0·69	0·79	..	0·01	0·01	0·79	0·78	0·78
August .	0·95	0·94	1·04	..	..	..	1·04	1·04	1·04
Total .	22·29	22·63	23 61	10·64	12·58	11·72	12·97	11·03	11·89
1887–8.									
September .	2·99	3·02	3·11	0·36	0·26	0·19	2·75	2·85	2·92
October . .	1·57	1·57	1·69	0·35	0·26	0·20	1·34	1·43	1·49
November .	3·27	3·34	3·41	2·70	2·82	2·65	0·71	0·59	0·76
December .	1·54	1·53	1·66	1·19	1·31	1·23	0·47	0·35	0·43
January . .	0·80	0·81	0·94	0·46	0·56	0·50	0·48	0·38	0·44
February .	0·97	0·88	1·03	0·27	0·43	0·45	0·76	0·60	0·58
March . .	2·97	2·98	3·13	3·16	4·05	3·99	−0·03	−0·92	−0·86
April . .	2·03	2·02	2·14	0·76	0·93	0·88	1·38	1·21	1·26
May . . .	1·21	1·23	1·28	0·07	0·09	0·09	1·21	1·19	1·19
June . . .	4·74	4·75	4·87	2·38	2·49	2·40	2 49	2·38	2·47
July . . .	3·59	3·75	3·86	0·76	0·83	0·68	3·10	3·03	3·18
August . .	3·14	3·23	3·38	1·50	1·55	1·41	1·88	1·83	1·97
Total .	28·82	29·11	30·50	13·96	15·58	14·67	16·54	14·92	15·83

[1] Calculated on the rainfall shown by the $\frac{1}{1000}$th acre gauge. When the drainage exceeds the rainfall the difference is entered as a minus quantity.

EXPERIMENTS ON RAINFALL AND DRAINAGE AT ROTHAMSTED.

Monthly Record for each Harvest-year, Sept. 1 to Aug. 31.

—	Rainfall.			Drainage through soil (uncropped).			Difference,[1] approximately = evaporation.		
	8-Inch Funnel Gauge.	5-Inch Funnel Gauge.	$\frac{1}{1000}$th Acre Gauge.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.	20 Inches Deep.	40 Inches Deep.	60 Inches Deep.
1888–9.									
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
September .	0·86	0·87	1·03	0·08	0·12	0·09	0·95	0·91	0·94
October . .	0 96	0·98	1·09	0·07	0·03	0·02	1·02	1·06	1·07
November .	4·34	4·37	4·45	3·51	3·51	3·29	0·94	0·94	1·16
December .	1·57	1·61	1·69	1·51	1·60	1·54	0·18	0·09	0·15
January . .	1·16	1·19	1·29	0·82	1·06	0·82	0·47	0·23	0·47
February .	1·82	1·80	1·95	1·53	1·74	1·61	0·42	0·21	0·34
March . .	1·77	1·80	1·89	0·83	0·85	0·82	1·06	1·04	1·07
April . .	2·36	2·39	2·47	0·35	0·42	0·35	2·12	2·05	2·12
May . . .	4·85	4·90	5·00	3·06	3·32	2·85	1·94	1·68	2·15
June . . .	1·28	1·21	1·38	0·41	0·53	0·47	0·97	0·85	0·91
July . . .	5·58	5·59	5·67	2·43	2·58	2·42	3·24	3·09	3·25
August . .	2·02	2·08	2·18	0·04	0·06	0·05	2·14	2·12	2·13
Total .	28·57	28·79	30·09	14·64	15·82	14·33	15·45	14·27	15 76
1889–90.									
September .	2·31	2·36	2·44	0·77	0·73	0·63	1·67	1·71	1·81
October . .	3·51	3·57	3·62	2·45	2·47	2·28	1·17	1·15	1·34
November .	1·12	1·14	1·21	0·93	0·98	0·91	0·28	0·23	0·30
December .	1·36	1·40	1·46	1·29	1·46	1·34	0·17	..	0·12
January . .	2·86	2·94	2·94	2·42	2·62	2·52	0·52	0·32	0·42
February .	0·74	0·75	0·82	0·48	0·60	0·54	0·34	0·22	0·28
March . .	2·71	2·75	2·78	1·71	1·83	1·69	1·07	0·95	1·09
April . .	1·23	1·22	1·31	0·01	0·06	0·06	1·30	1·25	1·25
May . . .	1·34	1·34	1·38	0·12	0 10	0·10	1·26	1·28	1·28
June . . .	2·33	2 36	2·40	0·06	0·03	0·04	2·34	2·37	2·36
July . . .	4 41	4·49	4·56	2·76	2·61	2·54	1·80	1·95	2·02
August . .	2 38	2·42	2·51	0·16	0·11	0·09	2·35	2·40	2·42
Total .	26·30	26·73	27·43	13·16	13·60	12·74	14·27	13·83	14·69

[1] Calculated on the rainfall shown by the $\frac{1}{1000}$th acre gauge.

NOTE BY DR. GILBERT.—These Tables, of which the first four were placed on the wall during the discussion, contain the results of the experiments on Rainfall and Drainage at Rothamsted for twenty harvest-years (September 1 to August 31), 1870–71 to 1889–90 inclusive. The rainfall is given as registered both by a 5-inch funnel-gauge, and by a specially made gauge of $\frac{1}{1500}$th of an acre area; also by an 8-inch gauge since the beginning of 1881. The drainage, or percolation results, represent the amounts of the rainfall passing through rather heavy uncropped soil, as shown by three "drain-gauges," each of $\frac{1}{1000}$th of an acre area, one with 20 inches, one with 40 inches, and one with 60 inches depth of soil, in its natural state of consolidation. Table A shows, for each of the twenty harvest-years, the total amount in inches, of rainfall by each gauge, of drainage or percolation, through 20 inches, 40 inches, and 60 inches of soil, and the difference approximately representing the evaporation. The evaporation was in all cases calculated on the rainfall shown by the $\frac{1}{1500}$th of an acre gauge. Table B shows, for each of the twelve months of the harvest-year, the average rainfall, drainage, and evaporation over the twenty years. Tables C and D are general summaries of the average results for the first ten, the second ten, and the total period of twenty years. The succeeding twenty Tables give, respectively, for each of the twenty harvest-years, the rainfall, drainage, and evaporation, for each month, and the total for the year. It should be explained that the funnel portion of the $\frac{1}{1500}$th of an acre rain-gauge is constructed of wood, lined with lead, the upper edge consisting of a vertical rim of plate-glass bevelled outwards. The rain is conducted by a tube into a galvanized iron cylinder underneath, and when this is full it overflows into a second cylinder, and so on into a third and fourth, and finally into an iron tank. Each of the four cylinders holds rain corresponding to ¼ an inch of depth, and the tank an amount equal to 2 inches. Each cylinder has a gauge-tube attached, graduated to read to 0·002 inch, but which can be read to 0·001 inch. Small quantities are transferred to a smaller cylinder, with a gauge-tube graduated to 0·001 inch. The three drain-gauges were constructed by digging a deep trench along the front, gradually undermining at the depth required, and putting in plates of cast-iron, with perforated holes, to support the mass. The iron plates were kept in place by iron girders, and the ends of the plates and of the girders supported by brickwork at the back and the two sides. Trenches were then dug round the block of soil, bit by bit, and it was gradually enclosed by walls of brick laid in cement. Below the perforated iron bottom a zinc funnel of the same area as the block of soil was finally fixed, and the drainage water was collected and measured in galvanized iron cylinders, with gauge-tubes, as in the case of the rain. These soil drain-gauges being kept without vegetation, their results are not directly applicable for estimating the amount of percolation over a drainage-area more or less covered with vegetation, and it had been suggested that they should be so covered. But this would sacrifice important results; and as the amount of evaporation is very different with different kinds of vegetation, the results with only three drain-gauges, and these with one description of soil, and of varying depth, would also be inapplicable for the purpose of directly estimating the percolation of a district. In 1874 a series of eighteen drain-gauges was arranged for the investigation of the influence of various crops, but unfortunately the specially made glazed stoneware cylinders, 24 inches diameter and 60 inches deep, were found not to be watertight, and hence the attempt was abandoned. About forty years ago, however, experiments of quite another kind were made at Rothamsted for several years in succession, to determine the amount of water

given off by plants during their growth, those selected including various individual agricultural plants, the mixed herbage of grass-land, and also evergreen and deciduous trees. The results afforded valuable data upon which to form a judgment as to the probable amounts of evaporation due to vegetation; and the indications so obtained, together with those of direct percolation experiments with and without vegetation, constitute the only evidence of a purely experimental kind at present available, as the basis of general estimates. It is, however, obviously desirable that estimates so founded should be studied in connection with those arrived at in other ways, such as by the gaugings of rivers and of wells.

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RESULTS OF EXPERIMENTS AT ROTHAMSTED

ON THE

QUESTION OF THE FIXATION OF FREE NITROGEN.[1]

FROM the results of the experiments of Boussingault, and also of those made at Rothamsted under conditions of sterilization and inclosure more than thirty years ago, Sir J. B. Lawes and the author had always concluded that at any rate our agricultural plants did not assimilate free nitrogen. They had also abundant evidence that the Papilionaceæ, as well as other plants, derived much nitrogen from the combined nitrogen in the soil and sub-soil. Still, they had long recognized that the source of the whole of the nitrogen of the Papilionaceæ was not explained; that there was, in fact, "*a missing link*"! They were, therefore, prepared to recognize the importance of the results first announced by Prof. Hellriegel in 1886; and they had hoped to commence experiments on the subject in 1887, but they had not been able to do so until 1888. Those first results showed a considerable formation of nodules on the roots, and coincidently great gain of nitrogen, in plants grown in sand (with the plant-ash) when it was microbe-seeded by a turbid watery extract of a rich soil.

In 1889 and since, they had made a more extended series. The plants were grown in pots in a glass-house.

[1] Abstract of a paper read before the Agricultural Chemistry Section of the Naturforscher Versammlung at Halle a.S., by Dr. J. H. Gilbert, F.R.S., September 24. 1891.

There were four pots of each description of plant, one with sterilized sand and the plant-ash, two with the same sand and ash, but microbe-seeded with watery extract, for some plants from a rich garden soil, for lupins from a sandy soil in which lupins were growing luxuriantly, and for some other plants from soil where the particular plant was growing. In all, in 1889 and subsequently, they had grown in this way four descriptions of annual plants —namely, peas, beans, vetches, and yellow lupins; and four descriptions of longer life—namely, white clover, red clover, sainfoin, and lucerne. Enlarged photographs of the above ground-growth, and of the roots, of the peas, the vetches, and the lupins, so grown, were exhibited. Without microbe-seeding there was neither nodule-formation nor any gain of nitrogen; but with microbe-seeding there was nodule-formation, and, coincidently, considerable gain of nitrogen.

As, however, in this exact quantitative series, the plants were not taken up until they were nearly ripe, it was obvious that the roots and their nodules could not be examined during growth, but only at the conclusion, when it was to be supposed that the contents of the nodules would be to a great extent exhausted. Another series was, therefore, undertaken, in which the same four annuals, and the same four plants of longer life, were grown in specially made pits, so arranged that some of the plants of each description could be taken up, and their roots and nodules studied, at successive periods of growth: the annuals at three periods—namely, first when active vegetation was well established, secondly when it was supposed that the point of maximum accumulation had been approximately reached, and thirdly when nearly ripe; and the plants of longer life at four periods—namely, at the end of the first year, and in the second year when active vegetation was re-established, when the point of maximum accumulation had been reached, and lastly when the seed was nearly ripe. Each of the eight descriptions of plant was grown in sand (with the plant-ash), watered with the extract from a rich soil; also in a mixture of two parts rich garden soil and one part of sand. In the sand the infection was comparatively local and limited, but some of the nodules developed to a great size on the roots of the weak plants so grown. In the rich soil the infection was much more general over the whole area of the roots, the nodules were much more numerous, but generally very much smaller. Eventually

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the nodules were picked off the roots, counted, weighed, and the dry substance and the nitrogen in them determined.

Taking the peas as typical of the annuals, and the sainfoin of the plants of longer life, the general result was, that at the third period of growth of the peas in sand the amount of dry matter of the nodules was very much diminished, the percentage of nitrogen in the dry matter was very much reduced, and the actual quantity of nitrogen remaining in the total nodules was also very much reduced. In fact the nitrogen of the nodules was almost exhausted. The peas grown in rich soil, however, maintained much more vegetative activity at the conclusion, and showed a very great increase in the number of nodules from the first to the third period; and with this there was also much more dry substance, and even a greater actual quantity of nitrogen, in the total nodules at the conclusion. Still, as in the peas grown in sand, the percentage of nitrogen in the dry substance of the nodules was very much reduced at the conclusion. In the case of the plant of longer life, the sainfoin, there was, both in sand and in soil, very great increase in the number of nodules, and in the actual amount of dry substance and of nitrogen in them, as the growth progressed. The percentage of nitrogen in the dry substance of the nodules also showed, even in the sand, comparatively little reduction, and in soil even an increase. In fact, separate analyses of nodules of different character, or in different conditions, showed that whilst some were more or less exhausted and contained a less percentage of nitrogen, others contained a high percentage, and were doubtless new and active. Thus, the results pointed to the interesting conclusion, that, in the case of the annual, when the seed is formed, and the plant more or less exhausted, both the actual amount of nitrogen in the nodules, and its percentage in the dry substance, are greatly reduced, but that, with the plant of longer life, although the earlier formed nodules become exhausted, others are constantly produced, thus providing for future growth.

As to the explanation of the fixation of free nitrogen, the facts at command did not favour the conclusion that under the influence of the symbiosis the higher plant itself was enabled to fix the free nitrogen of the air by its leaves. Nor did the evidence point to the conclusion that the nodule-bacteria became distributed through the soil and there fixed free nitrogen, the compounds of

nitrogen so produced being taken up by the higher plant. It seemed more consistent, both with experimental results and with general ideas, to suppose that the nodule-bacteria fixed free nitrogen within the plant, and that the higher plant absorbed the nitrogenous compounds produced. In other words, there was no evidence that the chlorophyllous plant itself fixed free nitrogen, or that the fixation takes place within the soil, but it was more probable that the lower organisms fix the free nitrogen. If this should eventually be established, we have to recognize a new power of living organisms—that of assimilating an elementary substance. But this would only be an extension of the fact that lower organisms are capable of performing assimilation-work which the higher cannot accomplish; whilst it would be a further instance of lower organisms serving the higher. Finally, it may here be observed that Loew has suggested that the vegetable cell, with its active protoplasm, if in an alkaline condition, might fix free nitrogen, with the formation of ammonium nitrite. Without passing any judgment on this point, it may be stated that it has frequently been found at Rothamsted that the contents of the nodules have a weak alkaline reaction when in apparently an active condition—that is, whilst still flesh-red and glistening.

As to the importance of the fixation for agriculture, and for vegetation generally, there is also much yet to learn. It is obvious that different Papilionaceæ growing under the same external conditions manifest very different susceptibility to, or power to take advantage of, the symbiosis. The fact, as shown by Prof. Nobbe, that Papilionaceous shrubs and trees, as well as herbaceous plants, are susceptible to the symbiosis, and under its influence may gain much nitrogen, is of interest from a scientific point of view as serving to explain the source of some of the combined nitrogen accumulated through ages on the surface of the globe; and also from a practical point of view, since, especially in tropical countries, such plants yield many important food materials, as well as other industrial products.

In conclusion, it will be seen that the experimental results which have been brought forward constitute only a small proportion of those already obtained or yet to be obtained at Rothamsted, but they have been selected as being to a great extent typical, and illustrative of the lines of investigation which are being carried out.

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THE SOURCES OF THE NITROGEN

OF

OUR LEGUMINOUS CROPS.

BY

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INTRODUCTION.

IT happens that the agricultural plants belonging to the great family of the *Leguminosæ* are all included within the sub-order *Papilionaceæ*. But, as the terms *Leguminosæ* and *leguminous* are better known in agricultural discussions, they will be adopted throughout this article. It will be seen farther on, however, that the limitation which the use of the terms *Papilionaceæ* and *papilionaceous* would imply, may possibly in the course of future investigation prove to be more appropriate, especially when the subject of the sources of the nitrogen of the plants of the different sub-divisions is in question (see p. 33).

There can be no doubt, that both the scientific interest, and the practical value, of our leguminous crops, depend very much on the amount of nitrogen which they contain, and on the sources of their nitrogen; and especially on the great differences

in these respects between them and the representatives of the other families of plants with which they are grown, either in alternation in our rotations, or in association in our meadows and pastures.

It is well known that, under the conditions in which crops are grown in ordinary agriculture, nitrogenous manures have very direct effects in increasing the produce of wheat, of barley, and of oats, of turnips, of mangel, and of potatoes. This is the case, notwithstanding that in the cereals the increased produce consists characteristically of the non-nitrogenous substances starch and cellulose; in the root-crops of the non-nitrogenous substance sugar; and in potatoes of the non-nitrogenous substance starch. Leguminous crops, on the other hand, not only as a rule accumulate much more nitrogen over a given area of land under equal soil conditions, and contain a higher percentage of nitrogen in their dry substance, than the crops above enumerated, but there is abundant evidence that they also derive much nitrogen from the combined nitrogen of the soil and subsoil, and further that they probably take up much as nitric acid; yet, it is generally recognised in practical agriculture, that direct nitrogenous manures have comparatively little effect in increasing the produce of such crops.

The influence of nitrogenous manures in increasing the production of the non-nitrogenous constituents of our crops is very strikingly illustrated by the results given in Table I. (p. 5).

The calculations are based on the average produce obtained in the experiments at Rothamsted by the different manures—of wheat over twenty years, of barley over twenty years, of sugar-beet over three years, of mangel-wurzel over eight years, of potatoes over ten years, and of beans over eight years.

As will be seen, the Table shows—the estimated amounts of carbon, per acre per annum, in the total produce (grain and straw) of wheat, and of barley, in the roots of sugar-beet and of mangel-wurzel, in the tubers of potatoes, and in the total produce (corn and straw) of beans, when each is grown by a complex mineral manure without nitrogen, and also when grown with the same mineral manure with nitrogenous manures in addition. Next is shown the estimated gain of carbon, that is, the increased amount of it accumulated in the crop under the influence of the

TABLE I.—*Estimates of the Yield and Gain of Carbon, and of the Increased Produce of Carbohydrates, per acre per annum, in various Crops.*

	Carbon		Carbohydrates	
	Actual	Gain	Gain	For 1 lb. nitrogen in manure
	lb.	lb.	lb.	lb.
***Wheat twenty years*, 1852–71.**				
Mineral manure	988	—	—	—
„ „ and 43 lb. nitrogen as ammonia	1,590	602	1,240	28·8
Mineral manure and 86 lb. nitrogen as ammonia	2,222	1,234	2,550	29·7
Mineral manure and 86 lb. nitrogen as nitrate	2,500	1,512	3,140	36·5
***Barley twenty years*, 1852–71.**				
Mineral manure	1,138	—	—	—
„ „ and 43 lb. nitrogen as ammonia	2,088	950	1,992	46·3
***Sugar-beet three years*, 1871–73.**				
Mineral manure	1,123	—	—	—
„ „ and 86 lb. nitrogen as ammonia	2,600	1,477	3,188	37·1
Mineral manure and 86 lb. nitrogen as nitrate	3,031	1,908	4,052	47·1
***Mangel-wurzel eight years*, 1876–83.**				
Mineral manure	759	—	—	—
„ „ and 86 lb. nitrogen as ammonia	1,889	1,130	2,376	27·6
Mineral manure and 86 lb. nitrogen as nitrate	2,129	1,370	2,771	32·2
***Potatoes ten years*, 1876–85.**				
Mineral manure	1,021	—	—	—
„ „ and 86 lb. nitrogen as ammonia	1,783	762	1,507	17·5
Mineral manure and 86 lb. nitrogen as nitrate	1,752	731	1,416	16·5
***Beans eight years*, 1862 *and* 1864–70**				
Mineral manure	726	—	—	—
„ „ and 86 lb. nitrogen as nitrate	992	266	474	5·5

nitrogenous manures. The estimated increased production of total carbohydrates, under the influence of the nitrogenous manures, is then given; and lastly, the estimated gain of carbohydrates for 1 lb. of nitrogen supplied in manure. Such estimates can obviously be only approximations to the truth; but, accepted as such, they are of interest and of use, as conveying some definite impression of the influence of nitrogenous manures on carbon-assimilation, and on carbohydrate-formation.[1]

It is seen that, independently of the underground growth, the wheat was estimated to assimilate 988 lb. of carbon per acre per annum, under the influence of a complex mineral manure alone; and that the amount was increased to 1,590 lb. by the addition of 43 lb. of nitrogen as ammonium-salts, to 2,222 lb. by 86 lb. of nitrogen as ammonium-salts, and to 2,500 lb. by 86 lb. of nitrogen as sodium-nitrate. Accordingly, as shown in the second column, the increased assimilation of carbon was, by 43 lb. of nitrogen as ammonium-salts 602 lb., by 86 lb. as ammonium-salts 1,234 lb., and by 86 lb. as sodium-nitrate 1,512 lb.

Reckoned in the same way, the increased assimilation of carbon in the barley was, for 43 lb. of nitrogen as ammonium-salts, 950 lb. per acre; that is, one-and-a-half time as much as by the same application in the case of wheat.

In the sugar-beet the increased assimilation of carbon, and accumulation of it in the roots, was 1,477 lb. per acre by the application of 86 lb. of nitrogen as ammonium-salts, and 1,908 lb. by 86 lb. of nitrogen as sodium-nitrate. There was, therefore, more increased assimilation of carbon and accumulation of it in the roots of the sugar-beet, than in the grain and the straw of wheat, by the same applications of nitrogenous manure.

In the mangel-wurzel the increased accumulation of carbon in the roots was 1,130 lb. by 86 lb. of nitrogen as ammonium-salts, and 1,370 lb. by 86 lb. as nitrate; that is, less than in the removed crops (corn and straw) of wheat, and considerably less than in the removed crops (the roots) of sugar-beet.

In the potatoes, reckoned on the increased production of tubers only (the tops being left on the land), the increased yield of carbon by 86 lb. of nitrogen as ammonium-salts was 762 lb.

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[1] The mode of calculating the amounts of carbon and of carbohydrates is as follows:—From the amount of dry substance in the crops the amounts of mineral matter and of nitrogenous substance are deducted, and the remainder represents approximately the amount of carbohydrates. The amount of carbon in the nitrogenous substance is calculated; and then that in the carbohydrates, on the assumption that, in the wheat, barley, and beans, starch and cellulose are the main products; in the sugar-beet and mangel-wurzel, cane-sugar, pectine, and cellulose; and in the potatoes, starch and cellulose.

per acre, and by 86 lb. as sodium-nitrate 731 lb. That is to say, there was considerably less increased production of starch in potatoes than of sugar in sugar-beet or mangel-wurzel, by the same applications of nitrogenous manure.

Lastly, in the leguminous crop—beans, with its high yield of nitrogen per acre, and the high percentage of nitrogen in its dry substance—the increased assimilation of carbon under the influence of nitrogenous manure was, comparatively, quite insignificant. Thus, there was, by the application of 86 lb. of nitrogen as sodium-nitrate, an increased assimilation of carbon of only 266 lb. per acre; or little more than one-sixth as much as in wheat, and little more than one-eighth as much as in sugar-beet, by the same application.

Turning to the figures in the third column of the Table on page 5, it is seen that there was a very greatly increased production of the non-nitrogenous bodies—the carbohydrates—by the use of nitrogenous manures.

Thus, by the use of 43 lb. of nitrogen as ammonium-salts, there was an estimated increase of 1,240 lb. of carbohydrates in the grain and straw of wheat, and of 1,992 lb. in those of barley. By the application of 86 lb. of nitrogen as ammonium-salts, there was an increased formation of 2,550 lb. of carbohydrates in wheat, of 3,188 lb. in sugar-beet, of 2,376 lb. in mangel-wurzel, and of only 1,507 lb. in potatoes; and when 86 lb. were applied as sodium-nitrate, there was an increased production of 3,140 lb. in wheat, of 4,052 lb. in sugar-beet, of 2,771 lb. in mangel-wurzel, and of only 1,416 lb. in potatoes; whilst, compared with these amounts, there was in beans, by the same application, an increase of only 474 lb. of carbohydrates.

The last column shows the estimated increased amounts of carbohydrates produced, for 1 lb. of nitrogen supplied in manure, in the different cases. Thus, when 43 lb. of nitrogen were applied as ammonium-salts, 1 lb. of nitrogen in manure gave an increased production of 28·8 lb. of carbohydrates in the grain and straw of wheat, and of 46·3 lb. in those of barley; when 86 lb. were applied as ammonium-salts, 1 lb. gave an increase of 29·7 lb. carbohydrates in the grain and straw of wheat, 37·1 lb. in the roots of sugar-beet, 27·6 lb. in those of mangel-wurzel, and 17·5 lb. in potatoes. Again, when 86 lb. were applied as sodium-nitrate, 1 lb. gave an increase of 36·5 lb. carbohydrates in wheat, 47·1 lb. in sugar-beet, 32·2 lb. in mangel-wurzel, 16·5 lb. in potatoes, and only 5·5 lb. in the leguminous crop—beans.

Thus, then, we have the apparently anomalous result, that the crops which are characterised by yielding a comparatively small amount of nitrogen over a given area, by containing a com-

paratively low percentage of nitrogen in their dry substance, and by yielding comparatively large amounts of the *non*-nitrogenous products—starch, sugar, and cellulose—are especially benefited by the application of nitrogenous manures, and under their influence yield greatly increased amounts of those non-nitrogenous bodies; whilst the leguminous crops, which contain a much higher percentage of nitrogen, and yield much more nitrogen over a given area of land, under the same soil and season conditions, are much less benefited by such manures.

Without attempting to give an adequate physiological explanation of this curious result, some of the facts bearing upon it may be briefly stated as follows: The non-leguminous crops having comparatively limited power of accumulating nitrogen under given soil conditions, they generally require nitrogenous manuring; the amount of nitrogen assimilated to a great extent rules the amount of chlorophyll formed; chlorophyll formation is an essential condition of carbon assimilation; the amount of carbon assimilated is the chief measure of the amount of produce; and since the more special or characteristic products of the non-leguminous crops are the non-nitrogenous substances—the carbohydrates, the natural result of the increased assimilation of nitrogen, and the consequent increased luxuriance, is an increased formation of the bodies which are their essential or characteristic products.

The fact is, that whilst it can hardly be said that there remains an unsolved problem in the matter of the sources of the nitrogen of our *non*-leguminous crops—of wheat, of barley, and of grasses, as representatives of the great family of the *Gramineæ*; of turnips, representing the *Cruciferæ*; of some varieties of beet, representing the *Chenopodiaceæ*; and of potatoes of the *Solaneæ*—it must be admitted to be quite otherwise so far as our leguminous crops are concerned.

It is nearly a century ago since the question whether plants took up, or evolved, free nitrogen, became a matter of experiment and of discussion; and it is just about half a century since Boussingault commenced experiments to determine whether plants assimilate free nitrogen. From his results he concluded that they did not; and those obtained at Rothamsted about thirty years ago confirmed the conclusions of Boussingault. In fact, we concluded that under the conditions of those experiments, which were those of sterilisation and enclosure, in which therefore the action both of electricity and of microbes was excluded, the results were conclusive against the supposition that, under such conditions, the higher chlorophyllous plants can directly fix free nitrogen, either by their leaves or otherwise.

It may, in fact, we think, be concluded that, at any rate in the case of our gramineous, our cruciferous, our chenopodiaceous, and our solaneous crops, free nitrogen is not the source. Nevertheless, we have long admitted that existing evidence was insufficient to explain the source of the whole of the nitrogen of the *Leguminosæ; that there was, in fact, a missing link!*

According to some even recent experimenters, however, gain of nitrogen is not limited to our leguminous crops; and the modes of explanation of the gains which have been observed are extremely various. Thus, it has been assumed: that *combined* nitrogen was absorbed from the air, either by the soil or by the plant; that there is fixation of free nitrogen within the soil by the agency of porous and alkaline bodies; that there is fixation by the plant itself; that there is fixation within the soil by the agency of electricity; and, finally, that there is fixation under the influence of micro-organisms within the soil, both with and without the accompanying growth of higher plants.

Limiting our discussion here mainly to the question of the sources of the nitrogen of the *Leguminosæ*, it may be said that this has been the subject of experiment and of controversy for about half a century, and it is generally admitted that all the evidence that has been acquired on lines of inquiry until recently followed, has failed to solve the problem. During the last few years, however, the discussion has assumed a somewhat different aspect. The question still is, whether free nitrogen is an important source of the nitrogen of vegetation generally, but especially of the *Leguminosæ*; but whilst few now assume that the higher chlorophyllous plants directly assimilate free nitrogen, it is nevertheless supposed to be brought under contribution in various ways; but especially by being brought into combination under the influence of micro-organisms, or of other low forms, either within the soil itself, or in symbiotic growth with a higher plant.

Of all the recent results bearing upon the subject, those of Hellriegel and Wilfarth with certain leguminous plants seem to us to be by far the most definite and significant; pointing to the conclusion that, although the higher chlorophyllous plants may not directly utilise free nitrogen, some of them, at any rate, may acquire nitrogen brought into combination under the influence of lower organisms; the development of which is, apparently, in some cases a coincident of the growth of the higher plant whose nutrition they are to serve.

It was in the Agricultural Chemistry Section of the "Naturforscher Versammlung" held in Berlin, in 1886, when one of

ourselves happened to be presiding, that Professor Hellriegel first announced his new results. Quite consistently, not only with common experience in agriculture, but also with the direct experimental results of ourselves and others, Hellriegel found, in his experiments, that plants of the gramineous, the chenopodiaceous, the polygonaceous, and the cruciferous families, depended on combined nitrogen supplied within the soil. On the other hand, he found that leguminous plants did not depend entirely on such supplies. His results were, indeed, not only very definite, but it is seen that they had a special bearing on the admittedly unsolved problem of the source of the whole of the nitrogen of leguminous crops.

Hellriegel's experiments and results may be briefly described as follows:—In 1883 he commenced a comprehensive series of vegetation experiments in pots, in which he grew agricultural plants of various families in washed quartz sand. To all the pots nutritive solutions, but containing no nitrogen, were added. To one series nothing else was supplied; to a second a fixed quantity of nitrogen as sodium-nitrate was added; to a third twice as much; and to a fourth, four times as much. The result was that, in the case of the *Gramineæ*, and some other plants, the growth was largely proportional to the combined nitrogen supplied, whilst in that of the *Leguminosæ* it was not so. In the case of these plants—that of peas, for example—it was observed that, in a series of pots to which no nitrogen was added, most of the plants were apparently limited in their growth by the amount of nitrogen which the seed supplied. Here and there, however, a plant growing under ostensibly the same conditions grew very luxuriantly; and, on examination, it was found that whilst no nodules were developed on the roots of the plants of limited growth, they were abundant on those of the luxuriantly grown plants.

In view of this result, Hellriegel, with his colleague Dr. Wilfarth, instituted experiments to determine whether, by the infection of the soil with appropriate organisms, the formation of the root-nodules and luxuriant growth could be induced; and whether, by the exclusion of such infection, the result could be prevented. To this end, they added to some of a series of experimental pots, 25 cubic centimetres, or sometimes 50 cubic centimetres, of the turbid watery extract of a fertile soil, made by shaking a given quantity of it with five times its weight of distilled water, and then allowing the solid matter to subside. In some cases, however, the extract was sterilised. In those in which it was not sterilised, there was almost always luxuriant growth, and abundant formation of root-nodules; but with sterilisation there was no such result. Consistent results were

obtained with peas, vetches, and some other *Leguminosæ*; but the application of the same soil-extract had little or no effect, in the case of lupins, serradella, and some other plants of the family, which are known to grow more naturally on sandy than on loamy or rich humus soils. Accordingly, they made a similar extract from a diluvial sandy soil, where lupins were growing well, in which it might be supposed that the organism peculiar to such a soil would be present; and, on the application of this to a nitrogen-free soil, lupins grew in it luxuriantly, and nodules were abundantly developed on their roots.

Further particulars of the experiments of Hellriegel and Wilfarth, and also of the results and conclusions of Berthelot, Dehérain, Joulie, Dietzell, Frank, Emil von Wolff, and Atwater, as well as of some of the later experiments of Boussingault which have a bearing on the present aspect of the question, will be found in our paper in the Philosophical Transactions, Vol. 180 (1889), B. A short account is also given of the experiments of Bréal, confirming the results of Hellriegel, in our paper in the "Proceedings of the Royal Society," Vol. 47, 1890.[1]

Thus, then, not only did Hellriegel and Wilfarth get negative results with plants of other families than the *Leguminosæ*, as all experience would lead us to expect, but they obtained positive results with the *Leguminosæ*, in regard to the source of the whole of the nitrogen of which experience showed that there was a "missing link." Such results were obviously of fundamental and of far-reaching importance; and it seemed desirable that the subject should be further investigated with a view to their confirmation or otherwise. Accordingly, it was decided to take it up at Rothamsted, and it was hoped to commence experiments in 1887, but it was not possible to do so until 1888. In that year, a preliminary series was undertaken; the investigation was continued in 1889 and 1890, and is, in fact, still in progress.

It is proposed to give in the following pages some account of the conditions, and of the results, of these recent experiments made at Rothamsted, which do show a fixation of free nitrogen. But, before doing so, it will be well to call attention to those of the earlier experiments, which did not indicate any fixation; as the well-defined difference in the conditions under which such different results were obtained will bring clearly to view what are the conditions under which fixation does, and what are those under which it does not, take place. We shall thus, too, be the better able to form some judgment as to the practical bearing of the recent results.

[1] A. Petermann found gain with lupins, but doubted whether it was entirely due to root-nodule action, or whether it was from the combined or the free nitrogen of the air. *Bull. Station Agron.* Gembloux (Belg.), March 1890.

Earlier Experiments, which did not show Fixation of Free Nitrogen.

It has already been stated, that the results and conclusions of Boussingault were against the supposition that plants assimilate the free nitrogen of the atmosphere. His numerous experiments on the subject were commenced in 1837, and were continued at intervals up to 1858. In all cases the substances he used as soil were sterilised; in some the supplied air was washed; whilst in others the plants grew in limited air, or were more or less protected. He experimented with a great variety of plants—wheat and oats representing *Graminecæ*; clover, peas, haricots, and lupins as *Leguminosæ*; also garden cress and sunflower.

In some of his earlier experiments, conducted in free air in a summer-house, the leguminous plants, trefoil and peas, did indicate some gain of nitrogen; but in all the subsequent experiments there was generally either a slight loss, or, if a gain, it was represented by only fractions, or low units, of milligrams; the larger amounts being with Leguminosæ, in free air, under a glazed case. After twenty years of varied and laborious investigation, M. Boussingault concluded that plants have not the power of assimilating the free nitrogen of the atmosphere.

Experiments on the subject were commenced at Rothamsted in 1857, they were continued for several years, and the late Dr. Pugh took a prominent part in the inquiry.

The soils used were ignited, washed, and re-ignited pumice or soil. The specially-made pots were ignited before use, and cooled over sulphuric acid under cover. Each pot, with its plants, was enclosed under a glass shade, which rested in the groove of a specially-made hard-baked glazed stoneware lute-vessel, mercury being the luting material. Under the shade, through the mercury, passed one tube for the admission of air, another for its exit, and another for the supply of water or solutions to the soil; and there was an outlet at the bottom of the lute-vessel for the escape of the condensed water into a bottle affixed for that purpose, from which it could be removed and returned to the soil at pleasure.

A stream of water being allowed to flow from a tank into a large stoneware Woulff's bottle, of more than 20 gallons capacity, the air passed from it by a tube, through two small glass Woulff's bottles containing sulphuric acid, then through a long tube filled with fragments of pumice saturated with sulphuric acid, and lastly through a Woulff's bottle containing a saturated solution of ignited carbonate of soda; and, after being so washed, the air

entered the glass shade, from which it passed, by the exit tube, through an eight-bulbed apparatus containing sulphuric acid, by which communication with the unwashed external air was prevented. Carbonic acid was supplied as required, by adding a measured quantity of hydrochloric acid to a bottle containing fragments of marble, the evolved gas passing through one of the bottles of sulphuric acid, through the long tube, and through the carbonate of soda solution, before entering the shade.

In 1857 twelve sets of such apparatus were employed; in 1858 a larger number, some with larger lute-vessels and shades; in 1859 six, and in 1860 also six. Each year the whole were arranged, side by side, on stands of brickwork, in the open air. The numerical results obtained in the experiments of 1857 and 1858 are summarised in Table II. (p. 14).

The upper part of the Table shows the results obtained in 1857 and 1858, in the experiments in which no combined nitrogen was supplied beyond that contained in the seed sown. The growth was extremely restricted under these conditions, and the figures in the table show that, neither with the *Gramineæ*, the *Leguminosæ*, nor the *Polygonaceæ* (buckwheat), was there in any case a gain of three milligrams of nitrogen. In most cases there was much less gain than this, or a slight loss. There was, in fact, nothing in the results to lead to the conclusion that either of these different descriptions of plant had assimilated free nitrogen.

The lower part of the Table shows the results obtained in the experiments in which the plants were supplied with known quantities of combined nitrogen, in the form of a solution of ammonium-sulphate, applied to the soil. The effect of this direct supply of combined nitrogen was to increase the growth in a very marked degree, especially in the case of the *Gramineæ*. The figures in the table show that the actual gains or losses of nitrogen ranged a little higher in these experiments, in which larger quantities were involved; but they are always represented by units of milligrams only, and the losses are higher than the gains. Further, the gains, such as they are, are all in the experiments with the *Gramineæ*, whilst there is in each case a loss with the *Leguminosæ*, and with the buckwheat. The losses, if beyond the limits that might be expected from experimental error, are doubtless due to decay of organic matter, fallen leaves, &c.

It should be stated that the growth was far more healthy with the *Gramineæ* than with the *Leguminosæ*, which are, even in the open field, very susceptible to vicissitudes of heat and moisture, and were found to be extremely so under the conditions of enclosure under glass shades. It might be objected, therefore, that the negative results with the *Leguminosæ* are not so conclusive

TABLE II.—*Summary of the Results of Experiments made at Rothamsted, in 1857 and 1858, to determine whether Plants assimilate free Nitrogen.*

			Nitrogen, gram.		
			In Seed, and Manure, if any.	In Plants, Pot, and Soil.	Gain or Loss.
With no combined Nitrogen supplied beyond that in the Seed sown.					
			gram.	gram.	gram.
Gramineæ	1857	Wheat	0·0080	0·0072	−0·0008
		Barley	0·0056	0·0072	+0·0016
		Barley	0 0056	0·0082	+0·0026
	1858	Wheat	0·0078	0·0081	+0·0003
		Barley	0·0057	0·0058	+0·0001
		Oats	0·0063	0·0056	−0·0007
	1858 A[1]	Wheat	0·0078	0·0078	0·0000
		Oats	0·0064	0·0063	−0·0001
Leguminosæ	1857	Beans	0·0796	0·0791	−0·0005
	1858	Beans	0·0750	0·0757	+0·0007
		Peas	0·0188	0·0167	−0·0021
Other plants	1858	Buckwheat	0·0200	0·0182	−0·0018
With combined Nitrogen supplied beyond that in the Seed sown.					
Gramineæ	1857	Wheat	0·0329	0·0383	+0·0054
		Wheat	0·0329	0·0331	+0·0002
		Barley	0·0326	0·0328	+0·0002
		Barley	0·0268	0·0337	+0·0069
	1858	Wheat	0·0548	0·0536	−0·0012
		Barley	0·0496	0·0464	−0·0032
		Oats	0·0312	0·0216	−0·0096
	1858 A[1]	Wheat	0·0268	0·0274	+0·0006
		Barley	0·0257	0·0242	−0·0015
		Oats	0·0260	0·0198	−0·0062
Leguminosæ	1858	Peas	0·0227	0 0211	−0·0016
		Clover	0·0712	0·0665	−0·0047
	1858 A[1]	Beans	0·0711	0·0655	−0·0056
Other plants	1858	Buckwheat	0·0308	0·0292	−0·0016

[1] These experiments were conducted in the apparatus of M. G. Ville.

as those with the *Gramineæ*. Nevertheless, we concluded, and still conclude, from the results of our own experiments, as Boussingault did from his, that neither the *Gramineæ* nor the *Leguminosæ* directly assimilate the free nitrogen of the air.

That, under the conditions described, the *Leguminosæ*, as well as the *Gramineæ*, can take up and assimilate already combined nitrogen supplied to them is well illustrated in the experiments made in 1860 with *Leguminosæ* alone. The series comprised three experiments with white haricot beans: No. 1 without any other supply of combined nitrogen than that in the seed; No. 2 with a fixed quantity of nitrogen applied as ammonium sulphate, and No. 3 with a fixed quantity supplied as nitrate; also three experiments with white lupins: No. 1, as with the haricots, without artificial supply of combined nitrogen; No. 2 with supply as ammonium sulphate, and No. 3 as nitrate. Each of these two descriptions of leguminous plant showed considerably increased growth under the influence both of ammonium sulphate and of nitrate—indeed, the growth was much more satisfactory than in the earlier experiments. Still, owing to the atmospheric conditions within the shades, as above referred to, the plants lost both leaves and flowers, and were, therefore, taken up earlier than they otherwise would have been. The analytical results here again indicated no gain from free nitrogen, either in the experiments without, or in those with, an artificial supply of combined nitrogen—indeed, the losses were greater than the gains.

Such, then, were the negative results obtained when plants were grown under conditions of sterilisation and of enclosure. There was, under such conditions, no gain from free nitrogen, in the growth of either Gramineæ, Leguminosæ, or other plants.

Recent Experiments, which do show Fixation of Free Nitrogen.

It was about the year 1876, that M. Berthelot called in question the legitimacy of the conclusion that plants do not assimilate the free nitrogen of the air, when drawn from the results of experiments in which the plants are so enclosed as to exclude the possibility of electrical action; and more recently he has objected to experiments so conducted with sterilised materials, on the ground that, under such conditions, the presence, development, and action, of micro-organisms are excluded. So far, however, there is nothing in the recent results, either of M. Berthelot himself or of others, which can be held to invalidate the conclusion which had been drawn from the results of Boussingault, and from those obtained at Rothamsted, that the higher chlorophyllous plants do not directly assimilate free nitrogen.

Let us now consider what are the results obtained, when the conditions of growth involve neither sterilisation nor enclosure.

The Vegetation Experiments in 1888.

As already stated, it was in 1888 that the first of the recent experiments on the subject were made at Rothamsted. This preliminary series comprised experiments with peas, blue lupins, and yellow lupins. The peas were grown—

Pot 1. In washed sand, with the ashes of the plant added; but with no supply of combined nitrogen beyond a small determined amount in the washed sand, and that in the seed sown.

Pot 2. In similarly prepared sand (and ash), but microbe-seeded with 25 c.c. of the turbid watery extract from a rich garden soil.

Pot 3. Duplicate of No. 2.

Pot 4. In the rich garden soil itself.

Each of the two descriptions of lupins was grown—

Pot 1. In sand prepared as for the peas, but with lupin-plant-ash instead of pea-plant-ash added.

Pot 2. In similar washed sand, &c., but seeded with 25 c.c. of the turbid watery extract from a sandy soil where lupins had grown luxuriantly.

Pot 3. In the lupin sandy soil itself.

Pot 4. In rich garden soil.

The twelve pots were arranged in a small greenhouse; and distilled water, free from ammonia, was used for watering.

The sand employed was a yellow sand from Flitwick, in Bedfordshire, such as is used by gardeners in the neighbourhood for potting. The stones and coarser portions were removed by sifting, the remainder was several times washed, first with well-water, and afterwards with distilled; then dried in a water-bath, and finally mixed with the plant-ash. It still contained 0·00266 per cent. of nitrogen.

The sandy soil from which the watery extract was made for microbe-seeding the pots where lupins were to grow, and which was used as the soil in experiment No. 3 with lupins, was obtained from land which had been reclaimed from a common in Suffolk, on which no corn crop would grow, but on which, when subsequently sown with blue lupins, they grew as high as the hurdles. Excepting that visible organic matter was removed by sifting and picking, it was used as received, in which state it contained 0·0859 per cent. of nitrogen.

The garden soil contained 10·12 per cent. of moisture, and 0·3919 per cent. of nitrogen, corresponding to 0·4360 per cent. on the soil dried at 100° C.

The pots used were made of glazed earthenware. They had a hole half an inch in diameter at the bottom for drainage; and another at the side, near the bottom, for aëration, into which a glass tube bent upwards, and lightly closed with cotton-wool to exclude insects, was fixed. The pots rested on slips of thick sheet glass, placed in basins of the same glazed earthenware as the pots.

The plant-ashes used as mineral nutriment were prepared by suspension in distilled water, adding sulphuric acid to the point of neutralisation, evaporating to dryness, and gently re-igniting.

The drain hole at the bottom of each pot was loosely covered with a piece of thick glass, and 1 lb. of broken, washed, and dried flint was then put in. The pots held from 7 to 9 lb. of the yellow sand, from 6 to 7 lb. of the lupin sand, and about 4½ lb. of the garden soil.

The soil-extracts supposed to supply the organisms were made by shaking, in a stoppered bottle, one part of the garden soil or lupin sand, with five parts of distilled water, and, after subsidence, pouring off the turbid liquid, which was then passed through platinum gauze to separate any floating matter. Determinations of nitric nitrogen by Schloesing's method, and of total nitrogen by copper oxide, showed that the 25 c.c. of the garden-soil extract used for microbe-seeding contained little more than three-quarters of a milligram, and the 25 c.c. of the lupin-sand extract little more than a quarter of a milligram, of nitrogen—quantities which are quite immaterial considered as a supply of combined nitrogen.

The seeds were selected for sowing and for analysis by weighing three or four lots of a hundred each to ascertain the average weight per seed, and then a number of single seeds weighing within five milligrams of the mean weight were taken.

It was intended to commence the experiments early in the summer; but owing to the pressure of other work the necessary preparations were not completed until early in August. All the seeds were sown on August 6, three accurately weighed seeds being put into each pot.

From the first the peas germinated and grew well in each of the four pots; but in each of the four of blue lupins, and in each of the four of yellow lupins, one or more seeds failed, and had to be replaced; and in some cases these also failed. It is admittedly very difficult to secure healthy growth with lupins in pots. One essential condition seems to be that the soil must be kept open and porous; and it is also important that the mineral matter added to the soil should be quite neutral.

In the experiments of 1888, the growth was not satisfactory with either blue or yellow lupins; but, as will be seen farther on, it was so with yellow lupins in 1889. It would, therefore, be a waste of time and space to go into the details, either of the above-ground growth, the root-development, or the analyses, of the lupins of 1888; and attention will be confined here to the results obtained with peas in 1888, which, it will be seen, afford very important indications.

As already said, the peas in each of the four pots germinated and grew well. Those in the garden-soil were throughout the most luxuriant. Pots 2 and 3 were each seeded with 25 c.c. of the garden-soil-extract on August 13—that is, just a week after the sowing of the seed.

For some time the plants in pot 1, in the sand without soil-extract, showed more growth, and better colour, than those in either pot 2 or pot 3 with the soil-extract seeding. It was, in fact, not until four or five weeks after the seeding with the soil-extract that the plants in pots 2 and 3 began to show a darker green colour than those in pot 1 without soil-extract. The indication was, however, then so striking that, on September 25, it was decided to count the leaves, and to estimate, approximately, the relative area of leaf-surface of the plants in the different pots. For this purpose the leaves were classified into those which were bright green, those which were changing colour, and those which were withered. It will suffice to show the number, and the estimated relative area, of the total leaves in each case, on September 25, when the first counting and estimates were made, on October 17, on November 14, and on December 14, when the plants were cut. The following table summarises the results.

TABLE III.—PEAS, 1888. *Total number of Leaves, and Estimated relative Leaf Surface, those of the Plants in Pot* 1 (*without Soil-extract Seeding*), *on September* 25, *being taken as* 100.

	Number of Leaves				Estimated relative Leaf Surface			
	Pot 1	Pot 2	Pot 3	Pot 4	Pot 1	Pot 2	Pot 3	Pot 4
September 25 . . .	144	140	120	164	100	67	58	128
October 17	188	200	184	216	143	172	158	242
November 14 . . .	244	300	244	280	170	249	245	338
December 14 . . .	382	540	390	434	267	481	434	463

Thus, on September 25, after the plants in pots 2 and 3, with the soil-extract seeding, had begun to show a darker green

colour, they nevertheless showed both a less number of leaves, and considerably less leaf-surface, than the plants in pot 1 without the soil-extract. A possible explanation of the fact that the plants with the soil-extract seeding remained so long in a comparatively backward condition may be that, in the early stages of the development of the nodules and their contents, they rely largely for their nitrogenous nutriment on the compounds of nitrogen already within the plant, and so the development of the higher plant itself is retarded. The figures show, however, that from this date, the plants in pots 2 and 3, with the soil-extract, gradually gained upon those in pot 1 without it, both in number of leaves and in leaf-surface; until, when the plants were taken up on December 14, those in pots 2 and 3 showed 540 and 390 leaves, against only 382 on those in pot 1; and 481 and 434 of leaf-surface, against only 267 in pot 1. There is, therefore, clear evidence of increased growth under the influence of the soil-extract seeding.

In all the pots the upper portions of the plants obviously developed at the expense of the lower, the leaves of which gradually lost colour and withered, whilst the stems and leaves of the upper portion increased in growth; those in pots 2, 3, and 4, continuing to vegetate and to maintain a bright green colour to the last, whilst those in pot 1 showed more exhaustion, and maintained much less colour. Probably owing to the lateness of the season, there was no indication of flowering in any of the pots.

The four pots of plants were photographed on September 1, September 22, October 6, and lastly on November 3, about five weeks before the taking up of the plants.

As the roots had to be preserved without any loss for analysis, the examination of them had to be very carefully conducted, and was necessarily more restricted than if examination had been the only object. After the above-ground growth had been cut off, the pots, with their moist soil and roots, were kept in a warm dry place until the examination commenced. The block of soil was carefully turned out on to glazed cartridge-paper, and notes were at once taken as to the distribution of roots so far as it was then apparent. The sand or soil was then removed little by little until the roots were left nearly bare. Further notes were then taken, after which the remaining sand or soil was removed as far as possible by washing in a beaker with a little distilled water. The roots were then mounted upon paper, and so photographed, and finally noted upon.

In order to stimulate and assist the observation of others, it will be well to give some description of the development of the roots, and of the nodules on them, of the various experimental

plants, for, as will be seen, the differences in these respects are very great with different descriptions of plant, and under the different conditions of growth.

The roots of the peas in pot 1, with the washed and dried, but not sterilised, yellow sand, showed a densely matted mass of fibre, by far the greater portion of which was accumulated within the top four inches; and, notwithstanding there was no soil-extract seeding, there were many nodules on the roots, but fewer, and generally much smaller, than on those grown with the soil-extract seeding. They were also less characteristically accumulated near the surface, and more distributed along the root fibres. There were, however, some agglomerations of nodules. Comparing this result with that obtained in 1889, with a purer and sterilised sand, in which case there were no nodules, there can be little doubt that the development of nodules, and the fairly luxuriant growth in this pot without soil-extract seeding, are to be attributed to the impurity and non-sterilisation of the sand.

The roots in pot 2, with soil-extract seeding, also showed a dense mass of fibre, which, however, extended from the top to the bottom of the sand, penetrated the layer of flints, and distributed over the bottom of the pot. The roots were, in fact, much more generally distributed and less accumulated within the surface layers than in pot 1. The most developed root had three large agglomerated nodules, each with some scores of protuberances, somewhat as on a raspberry or mulberry. The other plants also showed similar nodules, but of a smaller size. There were also a number of small clusters distributed over the rootlets, but very few single nodules, differing in this respect from the development observed in pot 1.

In pot 3, also with soil-extract seeding, each of the three plants developed a mass of root-fibre extending throughout the sand, but less near the bottom. There were large agglomerations of nodules on the roots of each plant. There were, besides, many small clusters, and here and there single nodules. By far the most of the nodules were within the top three inches of the sand, but one considerable bunch was found as low as four inches from the surface. As in the other cases, the nodules were grey, and much lighter in colour than the roots on which they grew.

Each of the three plants in pot 4, with the garden soil, had a stouter main root than any of those in the other pots. From the side branches there proceeded a large amount of fine root-fibres which extended throughout the whole soil, those from the different plants being much interwoven. The roots extended round the sides and along the bottom of the pot, much more

than in either of the other pots. There were three small clusters of nodules on the roots of each of the three plants, one or two small bunches, and here and there a single nodule. But the clusters were much smaller, the total number of nodules was much less, and they were more generally distributed over the roots in this pot with rich garden soil than in either of the others, even than in pot 1 without soil-extract seeding. The root development was, however, as the description shows, much greater than in either of the other pots. There was, then, a greater development of root and root-fibre, but a less development of root nodules, in the garden soil, which itself supplied an abundance of combined nitrogen, as well as other nutriment.

Upon the whole, the evidence relating to the peas clearly shows that there was a greatly enhanced development of nodules on the roots under the influence of the soil-extract seeding, and, coincidently with this, considerably increased growth.

The nitrogen was determined in the sand and in the garden soil, at the commencement and at the conclusion of the experiments; also in the seed, in the above-ground growth (stems and leaves), and in the roots, separately. The dry matter and ash were also determined, in the seed, and in the produce grown.

It is of interest to remark (though the results are not here given) that the above-ground produce of the plants in pot 1, with the most restricted growth, and which from their pale colour indicated nitrogen-exhaustion, showed a lower percentage of nitrogen in its dry substance than was found in that of either of the other pots. It may be added that the roots in pots 2 and 3, with the soil-extract, and with so much greater development of nodules than on those in either pots 1 or 4, also contained a considerably higher percentage of nitrogen in their dry substance.

The next Table (IV.) shows the actual quantities of dry substance and of nitrogen in the separated and in the total products of growth.

TABLE IV.—PEAS, 1888.

	Dry substance			Nitrogen		
	In stems and leaves	In roots	In whole plant	In stem and leaves	In roots	In whole plant
	grams.	grams.	grams.	gram.	gram.	gram.
Pot 1. Sand without soil-extract . . .	7·423	2·600	10·023	0·2153	0·0669	0·2822
Pot 2. „ with soil-extract	9·368	2·409	11·777	0·4591	0·0770	0·5361
Pot 3. „ „ „	9·411	1·748	11·159	0·3770	0·0587	0·4357
Pot 4. Garden soil	12·808	2·846	15·654	0·5806	0·0794	0·6600

It is seen that there is more dry substance in the above-ground growth, but less remaining in the roots, in pots 2 and 3 with the soil-extract, than in pot 1 without it. In the whole plant there is about 10 grams of dry substance in pot 1 without soil-extract, against about 11¾ grams in pot 2, and more than 11 grams in pot 3, each with soil-extract.

The point of chief interest is, however, that there was in one case more than twice, and in the other nearly twice, as much nitrogen in the above-ground growth in pots 2 and 3 with the soil-extract seeding, as in pot 1 without it. But there was much less difference in the amounts remaining in the roots under the different conditions. Of nitrogen in the total vegetable matter grown, there is, in pot 2 nearly twice, and in pot 3 more than 1½ time, as much as in pot 1 without the soil-extract. In pot 4, with garden soil, and with therefore full supply of already combined nitrogen, there was more dry substance produced, and more nitrogen assimilated, than under the influence of the soil-extract seeding.

The significance of the results relating to the nitrogen is, however, more clearly seen in the next Table (V.), which shows the amounts in the soil at the commencement and at the conclusion of the experiment, and the gain or loss; the amounts in the seed, in the total products of growth, and the gain; the total nitrogen in the soil and seed at the commencement, in the soil and produce at the conclusion, and the gain. The Table also shows, in the last column but one, the nitrogen in the total products, reckoning the total initial nitrogen = 1; and in the last column, the amount in the plants, reckoning that in the seed = 1.

TABLE V.—PEAS, 1888.

—	Nitrogen										
	In sand or soil			In seeds and produce			Total			In total products, total initial = 1	In plants, nitrogen in seed = 1
	At commencement	At conclusion	Gain (+) or loss (−)	In seeds sown	In total plants	Gain	At commencement	At conclusion	Gain		
	grams.	grams.	gram.	gram.	gram.	gram.	grams.	grams.	gram.		
Pot 1	0·0999	0·1096	+0·0097	0·0293	0·2822	0·2529	0·1292	0·3918	0·2626	3·03	9·63
Pot 2	0·0999	0·0974	−0·0025	0·0298	0·5361	0·5063	0·1297	0·6335	0·5038	4·88	17·99
Pot 3	0·0999	0·0848	−0·0151	0·0291	0·4357	0·4066	0·1290	0·5205	0·3915	4·04	14·97
Pot 4	7·9989	7·9989	—	0·0301	0·8600	0·6299	8·0290	8·6589	0·6299	1·08	21·93

The first point to notice is, that there is very little difference in the amount of nitrogen in the sand or soil at the commencement and at the conclusion of the experiments. There would

doubtless, be some fine root-fibre not removed at the conclusion, so that where there is loss it is to be supposed that some of the original nitrogen of the sand has contributed to the growth. In the case of the garden-soil, with its high percentage of nitrogen, it is, of course, not impossible that there may have been some loss by the evolution of free nitrogen.

That there is at any rate no material gain of nitrogen in the sand or soil would seem to be confirmatory of the conclusion indicated by other evidence, that the fixation is not effected by the organisms within the soil, independently of the symbiotic growth of the nodules and their contents, and of the higher plant to which they are attached, and to whose nitrogenous supply they seem to contribute. Indeed, if the fixation had taken place under the influence of microbes within the soil, independently of connection with the higher plant, we should expect some accumulation within it, or we should have to conclude that the plant had availed itself of exactly the whole of the nitrogen so brought into combination—a supposition for which there would seem no reasonable justification.

Turning to the middle division of the Table, which shows the nitrogen in the seed sown, in the total vegetable matter grown, and the gain, and disregarding the changes in the soils, which it has been seen may well be done, it will be observed that, in the case of pots 1, 2, and 3, with sand, the gain in the plants is so large as to be very far beyond the limit of any possible experimental error. This certainly cannot be said of some of the experiments which have been conducted on other lines in regard to the question of the fixation of free nitrogen.

The gain of nitrogen in these initiative experiments is, however, much less than in many of those of Hellriegel and Wilfarth, and also much less than in subsequent experiments at Rothamsted. This is not to be wondered at when the late period of the season, and the consequent character of the growth, are borne in mind.

To refer to the figures, it is seen that, whilst the nitrogen supplied in the seed was only 0·03 gram or less, that in the products of growth was 0·2822 gram in pot 1, 0·5361 in pot 2, 0·4357 in pot 3, and 0·6600 in pot 4; and the gains were more than $\frac{1}{4}$ of a gram in pot 1, more than $\frac{1}{2}$ a gram in pot 2, about $\frac{3}{5}$ths of a gram in pot 3, and more than $\frac{3}{5}$ths of a gram in pot 4.

The third division of the Table shows the total nitrogen at the commencement (in soil and seed together), at the conclusion (in soil and total vegetable matter grown), and the gains.

But the significance of the results is more clearly seen in

the last two columns. The first of these shows the relation of the amount of nitrogen in the total products (soil and plants together) to the total initial nitrogen (soil and seed together), taken as 1. Even in pot 1, with the impure and not sterilised sand, but without soil-extract, there was, so reckoned, more than three times as much nitrogen in the products as in the soil and seed; in pot 2, with soil-extract seeding, there was nearly five times as much; and in pot 3, also with soil-extract, there was more than four times as much. In the case of pot 4, however, with garden soil, owing to the large amount of initial nitrogen in the soil, the gain, though actually large, appears when so reckoned but small.

It is in the last column of the Table, in which, disregarding the nitrogen in the soils, which was so nearly the same at the beginning and at the end, and reckoning the relation of the nitrogen in the total products of growth to that in the seed taken as 1, that the large amount of fixation is clearly brought to view. So reckoned, the nitrogen in the substance grown to that in the seed sown was: in pot 1, 9½-fold; in pot 2, nearly 18-fold; in pot 3 nearly 15-fold; and in pot 4, nearly 22-fold.

Here, then, under non-sterilised conditions—in fact, with suitable microbe-infection of the soil—there was very considerable fixation of free nitrogen.

The Vegetation Experiments in 1889, 1890, *and* 1891.

Since 1888 more extensive series of experiments have been made, on substantially the same lines as those already described. In 1889 peas, vetches, blue lupins, yellow lupins, red clover, and lucerne were sown; and in 1890 beans, white clover, and sainfoin. Excluding the blue lupins, which failed, it will be seen that the series included experiments with four annuals, namely, peas, vetches, beans, and yellow lupins; also with four plants of longer life, namely, white clover, red clover, sainfoin, and lucerne. And, as will be seen further on, experiments with the same four annuals, and the same four plants of longer life, were commenced in 1890, of which some are still in progress, on somewhat different lines from those above referred to, with a view to the investigation of some points of importance, which the necessary conditions of growth and subsequent treatment of the plants in the glass-house did not admit of.

Referring to the experiments in the glass-house, it may be stated that for the lupins, the sainfoin, and the lucerne, specially-made pots of glazed earthenware were employed. They were

about six inches in diameter, and fifteen inches deep inside; that is, about twice as deep as those used in 1888, and again in 1889 and 1890, for the peas, vetches, beans, white clover, and red clover. These larger pots had holes at the bottom for drainage, and slits at the sides, near the bottom, for aëration. Each of the pots, large or small, stood in a specially-made pan of the same material. A quantity of broken, washed, and this time ignited, flint was put into the bottom of each pot. The sand used was a rather coarse white quartz sand, from which the coarser and the finer portions were removed by sifting, and more of the finer by washing and decantation, first with well, and afterwards with distilled, water. In defect of means for igniting so large a quantity of material (several hundred pounds in all), without running the risk of gaining more impurity than was expelled, the portion retained for use was kept, in successive lots, in a large water-bath, at nearly 100° C., for several days, and then preserved in well-closed bottles. The results have shown that the sand so prepared was sufficiently, if not absolutely, sterilised.

In all the experiments commenced subsequently to 1888 the sand was mixed with only 0·1 per cent. of the plant ash and 0·1 per cent. of calcium carbonate.

There were four pots of each description of plant, excepting in the case of the white clover, of which there were five. For the peas, vetches, beans, white clover, red clover, sainfoin, and lucerne, No. 1 was with the prepared quartz sand, without soil-extract; Nos. 2 and 3 were with the quartz sand and garden soil-extract added; and No. 4 was with the garden soil itself; the fifth pot of white clover receiving calcium nitrate instead of soil-extract. Of the lupins (both blue and yellow), No. 1 was with the prepared quartz sand, without soil-extract; Nos. 2 and 3 were with lupin soil-extract added; and No. 4 was with the lupin sandy soil itself, to which 0·01 per cent. of the plant ash was added.

The soil-extracts were added the day before the sowing of the seed; 25 c.c. in the case of the plants grown in the smaller, and 50 c.c. in that of those grown in the larger, pots.

The seeds were selected and weighed as in 1888.

The analytical details relating to the experiments commenced in 1889, and subsequently, are not yet completed; nor have those already available yet been arranged and published, so that numerical results cannot be given here. The following notes on growth, and descriptions of the plants and their roots, together with a general statement of the bearing of the analytical data in some cases, will, however, convey a clear idea of the im-

portance and of the significance of the results which have so far been obtained.

The peas were sown on July 10 (1889) two seeds being put into each of the four pots; and the plants were taken up on October 23 and 24. Photographs of the four pots of plants were taken on August 3, August 20, September 27, and lastly on October 22; that is, the day before taking up. Unlike the result obtained in pot 1 in 1888 with impure and non-sterilised sand, the plants of 1889, in the purer and sterilised quartz sand, showed extremely limited growth. Before the end of July, those in both pots 2 and 3, with soil-extract seeding, began to show enhanced growth compared with that in pot 1, without the soil-extract; and, eventually, whilst the plants in pot 1 were only 8¼ and 8½ inches in height, those in pot 2, with soil-extract, were 14 and 50½ inches; and those in pot 3, also with soil-extract, were 40¼ and 39½ inches high. In pot 4, with the garden soil, the heights of the plants were 38½ and 41½ inches, or only about the same as in pot 3 with the soil-extract only. But the plants in pot 4 were more vigorous, and whilst they flowered and seeded, neither of those in either pot 2 or pot 3 did so, but continued to vegetate, the upper parts apparently at the expense of the lower.

Then as to the root development:—In pot 1, without soil-extract, and with extremely limited above-ground growth, it was altogether much less than in either pot 2 or pot 3 with soil-extract, or than in pot 4 with garden soil. Again, in pot 1, without soil-extract seeding, the main roots descended some distance before they threw out any considerable amount of root-branches and root-fibre; whereas, in pots 2 and 3, with soil-extract, there was characteristically much more fibre distributed both in the upper layers and throughout the pot.

It is specially to be noted that, whereas in pot 1 in 1888, with impure and non-sterilised sand, there was some development of nodules, now, in the pure and sterilised sand, not a nodule was observable.

In pot 2, with soil-extract seeding, one plant was very much larger than the other, and developed much more root. The smaller plant had, however, several nodules on the main root, near the surface of the soil, and a good many small ones distributed along the fibres. Most of the nodules were more or less shrivelled. The larger plant had a large cluster of nodules on the main root, very near the surface; and a very large number of single nodules, mostly small, was distributed on the root-fibres, quite to the bottom of the pot. Upon the whole those on the larger plant were less shrivelled.

In pot 3, also with soil-extract, and with two tall plants, the main roots extended to, and along, the bottom of the pot; throwing off many side branches, with a very large quantity of fine fibrous root. The greatest distribution was, however, in the upper few inches of the sand. There were two clusters of nodules on one of the plants, and three on the other, besides smaller bunches. A large number of mostly single small nodules was also distributed along the roots. On one of the plants the largest cluster was on the main root, and on the other the clusters were on the side branches.

In pot 4, with the garden soil, and not higher plants, but more vigorous and more matured growth than with sand and soil-extract only, there was a dense mass of root-fibre throughout the first six inches of depth. There were numerous nodules, the majority single and within the upper two or three inches of soil. There were also a few small bunches.

Thus, then, the limited growth in pot 1, with sand without soil-extract, was coincident with the entire absence of nodule-formation; and the increased growth in pots 2 and 3, with soil-extract, was coincident with a very great development of nodules. In pot 4, with garden soil, itself supplying abundance of combined nitrogen, there was also a considerable development of nodules, but distinctly less than in either pot 2 or pot 3, with sand and soil-extract only.

Lastly, without soil-extract, and without nodules, there was no gain of nitrogen; but, with soil-extract, and with nodule-formation, there was much gain of nitrogen; there being many times as much in the products of growth as in the seed sown.

The vetches were sown on July 10 (1889) two seeds being put into each pot; and the plants were taken up on October 26. The four pots of plants were photographed on August 3, August 20, September 27, and lastly on October 25, the day before being taken up.

As with the peas, the plants in pots 2 and 3 with sand and soil-extract had, before the end of July, shown more growth than those in pot 1 without it. Again, as with the peas, the vetches in the pure and sterilised sand showed extremely limited growth. On the other hand, those in pots 2 and 3, with the soil-extract, grew to a great height—indeed, higher than those in pot 4 with the garden soil. The heights of the plants were: in pot 1, without soil-extract, 11¼ and 10½ inches; in pot 2, with soil-extract, 52½ and 67 inches; in pot 3, also with soil-extract, 62½ and 51 inches; but in pot 4, with garden soil, only 53 and 36 inches. But, as in the case of the peas, whilst the plants in pot 4, with

the garden soil, flowered and seeded, those in pots 2 and 3, with sand and the soil-extract only, did not, but continued to vegetate, extending upwards, the higher and newer portions apparently at the expense of the lower and older parts of the plant.

In pot 1, with sand without soil-extract, and with very limited above-ground growth, there was much less development of root than in either pot 2 or pot 3 with soil-extract, or than in pot 4 with the garden soil. The main roots descended to the bottom of the pot, and threw out a number of side branches, but there was a marked deficiency of root-fibre; and not a single nodule was formed.

In pot 2, with soil-extract seeding, and very extended above-ground growth, there was a dense mass of root and root-fibre, which distributed throughout the pot, though the greatest accumulation was within the first three inches of depth. There were numerous nodules, but considerably less in quantity than on the corresponding pea roots. They were mostly single, and the greater number were found in the lower layers, which is also contrary to the result with the peas. They were, moreover, generally exceedingly small.

In pot 3, also with soil-extract, and with very extended above-ground growth, there was also an immense development of root and root-fibre, through the whole area of the sand; the greatest accumulation being in the upper and lower portions of the pot, with less in the middle. There were again many nodules, but very small, and probably fewer than on the roots in pot 2. All the nodules were single, and fairly distributed over the whole root area.

In pot 4, with garden soil, and, as with the peas, less extended but more vigorous and more matured growth than in sand with soil-extract only, there was a moderate amount of root and of root-fibre, chiefly within the upper six inches of depth; but there was altogether very much less of root development than in either pot 2 or pot 3, with the sand and soil-extract. There were many nodules, but all single and very small; and they appeared to be flattened, as if exhausted of their contents.

Here, then, with the vetches, as with the peas, the very restricted above-ground growth in pot 1, without soil-extract seeding, was associated with very limited root development, and with the entire absence of nodule-formation. On the other hand, the greatly extended vegetative growth in pots 2 and 3, with soil-extract, was associated with an immense development of root and root-fibre, and with the formation of numerous nodules. Again, in the garden soil, with its liberal supply of combined nitrogen, there was much less development of roots,

and less also of nodules, than in the pots with sand and soil-extract only.

Lastly, without soil-extract seeding, and with no nodules, there was no gain of nitrogen; whilst, with soil-extract, and with numerous nodules, there was considerable gain of nitrogen; there being, with much less nitrogen in the seed, and about the same amount in the products, as in the corresponding experiments with peas, very many times as much nitrogen in the vegetable matter produced as in the seed sown.

As already said, the experiments with blue lupins failed. Those with yellow lupins, however, gave very striking results.

As in the case of the other plants grown in 1889, the yellow lupin seeds were sown on July 10, three being put into each pot. There were some re-sowings, some seeds taken out, and eventually two plants were left in each pot. By the end of July the plants in pots 2 and 3, with the lupin soil-extract seeding, already showed more growth than those in pot 1 without it. Photographs of the plants were taken on August 3, August 20, September 27, October 28, and November 29; and the plants were taken up on December 7.

The plants in pot 1, with sand without soil-extract seeding, scarcely appeared above the rim of the pot, one being only about $1\frac{1}{2}$, and the other only $2\frac{3}{4}$ inches high. In pot 2, with lupin soil-extract seeding, one plant was about 24, and the other $18\frac{1}{2}$ inches high; both spreading much beyond the width of the pot. In pot 3, also with lupin soil-extract seeding, one plant was more than 24, but the other little more than 8 inches high. In fact, in both the pots, with quartz sand, ash, &c., and soil-extract seeding only, the plants developed considerably more than those in pot 4, with the lupin-soil itself; one of these being only about 16 inches, and the other about $18\frac{1}{2}$ inches high, and both less branching than those in pots 2 and 3.

Unlike the peas and vetches, the yellow lupins with soil-extract seeding only, flowered and podded freely. Thus, in pot 2, one plant flowered only, but the other had nine small pods; and in pot 3, one had four large and three small pods, and the other a flower forming. There were also in pot 4, with lupin-soil, on one plant five pods, and on the other, six. The general result was that, in the quartz sand with lupin soil-extract seeding, the plants not only produced a great deal more vegetable matter than those in the lupin sand itself, but they as freely flowered and seeded.

In pot 1, without soil-extract, and very restricted above-ground growth, there was coincidently very little root develop-

ment; the main roots descended far down the deep pot almost without branching, but, at the bottom, a number of branches and a mass of root-fibre were produced; the root-fibres were fleshy and succulent. No root-swellings or nodules were found.

In pot 2, with the lupin soil-extract seeding, and luxuriant and maturing above-ground growth, there was, on the other hand, a very great development of root. Branches were thrown out throughout the whole length; and at their ends masses of fleshy fibres were formed, which were thickly coated with root-hairs. On the main root of one plant, about three inches down, there was a large swelling or nodule the size of a field bean; four inches lower there were three smaller ones on a side branch; ten inches down, there were three as large as peas; and lower still, there was another small swelling, more like the nodules found on other plants. The other plant had less root growth. One and a half inch down there was a swelling the size of a small pea; and between four and five inches lower there were three swellings, one as large as a bean, and the others about the size of a vetch seed. These swellings on the lupin roots, which were all on the main roots or thicker branches, were very different in appearance from the nodules on the pea and vetch roots. They were, as described, swellings, encasing the root where they grew.

In pot 3, also with lupin soil-extract seeding, the plant which showed both great above-ground luxuriance and great seed-forming tendency, developed an immense amount of branching root, with a great deal of root-fibre, which extended throughout the sand, but to a greater degree in the lower than in the upper half of the pot. The main root was woody near the top. The lower root-fibres were fleshy and thickly coated with root-hairs. There were several swellings or nodules on the main root below 5 inches; and lower down on a root branch there were several swellings; there being in all twelve on this plant. The roots of the less luxuriant and less matured plant were smaller and more meagrely developed; about 10 inches down there were two bunches of small nodules, and three single nodules; and a little lower on a side branch another small nodule.

With regard to the great development of the root-hairs on the fine fibrils of the roots in both pots 2 and 3, with quartz sand and lupin soil-extract seeding, it may be supposed that this was an effort to acquire mineral nutriment, in quantity commensurate with the large amount of nitrogen fixed, and of nitrogenous nutriment so rendered available to the plant.

In pot 4, with the lupin-soil itself, and less luxuriant above-ground growth, the distribution of root was also very different

from that in pots 2 and 3 with the soil-extract only. The main root, at a depth of 2 inches, threw out many thread-like branches, at the end of each of which there was a bundle of fine fibre. The lower fibres became thicker, and were white and fleshy; but they were without the marked development of root-hairs observed in such abundance in pots 2 and 3. Most of the root was within 6 inches of the surface, and there seemed to be none below 14 inches. One or two inches from the surface there were swellings on the main roots, which were less raised, but more spreading, than those on the roots in pots 2 and 3. There were also, on one side branch, six very small nodules.

To sum up in regard to the yellow lupins: in the sterilised quartz sand, without soil-extract seeding, the growth was extremely limited, both above and under ground. Under the influence of the lupin soil-extract seeding, the above-ground growth was not only very luxuriant, but the plants developed considerable maturing tendency, flowering and seeding freely. The development of the roots generally, and that of swellings or nodules on them, were also very marked. In pot 4, with the lupin-sand itself, which would supply a not immaterial amount of combined nitrogen, although the growth was fairly normal, it was, both above ground and within the soil, much less than in the pots with soil-extract only; and the development of nodules was also less. It is probable that the less growth in the lupin-sand itself, than in the quartz sand with soil-extract, was largely due to the much less porosity of the lupin soil, especially when watered.

Again, as with the peas and the vetches, so with the lupins, without soil-extract seeding, there was very limited growth, no formation of nodules, and no gain of nitrogen; but, with soil-extract seeding, there was luxuriant growth, abundant nodule-formation, and, coincidently, great gain of nitrogen. There was, in fact, very many times as much nitrogen in the products of growth as in the seed sown.

The foregoing results with peas, vetches, and yellow lupins, are very definite and very striking. They are abundantly illustrative of the fact that under the influence of suitable microbe-seeding of the soil, there is nodule-formation on the roots, and, coincidently, increased growth, and gain of nitrogen beyond that supplied in the soil and in the seed as combined nitrogen, presumably due to the fixation, in some way, of free nitrogen.[1]

[1] MM. Schloesing *fils* and Laurent have shown, by growing *Leguminosæ* in closed vessels, and by the analysis of the air before and after growth, that free nitrogen disappeared, in quantity closely corresponding to that gained in growth; thus establishing the fact that the source of the gain was free nitrogen (*Compt. Rend.* cxi. 750).

As already said, experiments were also made with a fourth annual, namely beans; and with four plants of longer life—white clover, red clover, sainfoin, and lucerne. With some of these the growth was not so satisfactory as with the peas, the vetches, and the yellow lupins; partly owing to failure to ensure suitable infection of the roots. But, with both clovers there will doubtless be considerable gain, especially with the white clover, which, however, is still growing.

In reference to the failure of growth in the cases where it was apparently due to failure to obtain suitable microbe infection, it has already been said, that Hellriegel at first found great difficulty in ensuring a good result with lupins, serradella, and some other plants, among which was red clover; and the failure to obtain good results at Rothamsted with both blue and yellow lupins in 1888, and with blue lupins in 1889, was doubtless partly due to the same cause.

As bearing upon this curious and interesting point, it will be well briefly to refer here to the experiments and results of Professor Nobbe on this subject.[1] He undertook an investigation, in the first place to determine whether leguminous trees, as well as our agricultural leguminous plants, were susceptible to microbe infection and nodule-formation; and secondly to ascertain whether there is one nodule-forming bacterium, or whether many bacteria have the property—each description of plant, or perhaps each group, having its special bacterium.

The plants he experimented upon were peas, yellow lupins, and beans; also, as trees, *Robinia pseudacacia* (locust tree), *Cytisus laburnum* (laburnum), and *Gleditschia triacantha* (honey locust). To each of these he applied microbe-seeding from various sources; in some cases only soil-extracts, and in others pure cultivations, either from soil-extracts, or from the root-nodules of different plants. When soil-extracts only were used the results were somewhat irregular. For example, with peas, a better result was obtained by the use of *Gleditschia*, *Robinia*, or *Cytisus*, soil-extract, than of pea soil-extract. With *Robinia*, on the other hand, the best result was obtained with *Robinia* soil-extract. But when pure cultivations were employed, the general result was that more effect was produced on any particular description of plant by the bacteria obtained from the same description, than by those derived from other descriptions. Thus, with peas, there was more produce, and more nitrogen assimilated, by the application of pure cultivations of pea nodule and pea soil bacteria, than by that of lupin nodule, lupin soil,

[1] *Versuche über die Stickstoff-Assimilation der Leguminosen.* F. Nobbe, E. Schmid, L. Hiltner, E. Hotter. Versuchs-Stationen, xxxix. 327.

Robinia nodule, or *Robinia* soil, bacteria. On the other hand, the *Robinia* nodule bacteria, which showed no action with peas, had marked effects on *Robinia*. Still, this did not apply in all cases, there being sometimes more produce, and more nitrogen gained, under the influence of the microbe infection from another than from the same description of plant. In some cases infection had more effect than manuring with ammonium-salts or nitrate. Nobbe concludes, however, that the results can leave no doubt that the pea and the *Robinia* bacteria have different physiological actions, which indicate, if not different species or varieties, at any rate different race or nutrition modifications.

Beyerinck also concludes that the various papilionaceous bacteria differ more than he had formerly supposed. Thus, he found that *Vicia Faba*, infected with the bacteria from *Ornithopus*, produced no nodules; and he considers that the difference between the bacteria of beans and serradella accounts for the fact that serradella had no nodules when growing in a garden between beans which had numerous nodules.

Of the three descriptions of leguminous trees upon which Nobbe experimented, the *Robinia* and the *Cytisus*, which are both of the papilionaceous sub-division of the leguminous family, were susceptible to microbe infection, and nodule-formation on their roots, and showed coincidently gain of nitrogen; but the *Gleditschia*, which is not papilionaceous, but of the sub-order *Cæsalpinieæ*, was quite indifferent to such infection, although both soil-extracts and pure cultivations from various sources were tried. On the other hand, it was found that the application of calcium nitrate and ammonium sulphate gave considerably increased growth. Nobbe observes that the roots of *Gleditschia* have a very thick covering which it would be at any rate difficult for the bacteria to penetrate; but whether the members of this group generally behave differently from the *Papilionaceæ* in this respect remains for future investigation to determine. It is at any rate of interest to note, that the only leguminous plant outside the papilionaceous sub-order which has yet been experimented upon has not been found susceptible to infection, or to have nodules on its roots.

Difference in the External Character of Leguminous Root-nodules.

The conclusion drawn from the experiments of Nobbe above cited—that there are various nodule-forming bacteria—is at any rate consistent with the descriptions which have been given

of the plants grown at Rothamsted in 1889, which have shown that the external appearance, and the distribution, of the root-nodules were very different in the case of the peas, the vetches, and the lupins. In that of the peas there were many of what may be called agglomerations of nodules, and comparatively few single ones distributed on the root-fibres. On the roots of the vetches there were comparatively few agglomerations or bunches, and more single nodules, pretty widely distributed along the root-fibres. The lupin roots, on the other hand, showed tubercular developments very different from those on either the pea or the vetch roots. Indeed, at the period of examination—that is, when the plants were nearly ripe—two apparently distinct kinds were observed, one of which, the most prevalent, has been spoken of as "swellings," and the other as "nodules." The "swellings" were chiefly on the main roots or the thicker branches; where they grew they encased the root entirely, and they had a shining and presumably impervious skin. The "nodules," on the other hand, were chiefly single, small, and distributed on the root-fibres.

Assuming that the so-called "swellings" (with their contents) on the roots of the lupins were the bodies which had exercised the functions of the "nodules" found on the roots of the other plants, it is to be concluded that, after the very luxuriant growth, and the flowering and seeding, their function was so far at an end, and they had become suberised. The other bodies on the lupin roots, distinguished in the detailed description as "nodules," indicated too meagre development to have had much share in the great amount of assimilation that had been accomplished. On the other hand, the "swellings," which, as has been said, were all on the main roots or thicker branches, were certainly very characteristic of the roots of the lupin plants which attained the greatest growth; and, assuming that they, with their contents, were really the effective bodies, it must be supposed that they had been formed where they were found whilst the root was still young, and had grown with its growth. In favour of this supposition is the fact that the increased growth from the soil-extract seeding commenced quite early in the life of the plants.

The nodules on the roots of lucerne growing in the field were observed at different periods of the season in 1887, and again quite recently on plants taken from the field for that purpose. They are quite different in general external character from those on any of the other plants that have been examined at Rothamsted. Instead of being more or less rounded, they have more the appearance of shoots or buds, much longer

than broad, sometimes single, but more often divided or branched, there being generally two or three, and sometimes as many as twenty, or even many more, in a bunch, joined at the base. They have, so far, not been observed on the main root, but only on the root-fibres, and less near the surface than within the range of the subsoil. In some cases such a tuft or bunch will be at the end of a fine fibre, by which it is connected with the main root. As the season advances these bodies become shrivelled, and are in fact empty shells.

Among the *Leguminosæ* growing in the mixed herbage of grass land, in 1868 nodules were observed on the root-fibres of *Lathyrus pratensis*, especially near the surface of the soil; on the ultimate root-fibres of *Trifolium pratense*; and on the smaller rootlets of *Trifolium repens*.

In the case of red clover growing in rotation on arable land, an abundance of nodules has been found, both near the surface and at a considerable depth. They are generally more or less globular or oval. Some found on the main roots were more like "swellings" than attached tubercles, not, however, encasing the root, but only on one side. The greater number are, however, small and distributed chiefly on the root-fibres. Again, on the plot of rich garden soil on which red clover has now been grown at Rothamsted for thirty-eight years in succession, very numerous nodules, chiefly globular and small, have been found on the roots—for the most part within the first few inches of soil, but some to the depth of a foot or more, diminishing, however, very much both in number and in size as the clayey subsoil was reached.

Obviously much more evidence than the foregoing few observations can supply is needed in regard to any difference in character, or relative prevalence, at different periods in the life and growth of the plant, and under different conditions of soil, both so far as mechanical state and porosity, and richness or otherwise in available supplies of combined nitrogen are concerned, before any clear conception can be attained of the connection between nodule-formation, luxuriance of growth, and gain of nitrogen. The subject in various aspects is being further investigated at Rothamsted, and some of the results so far obtained will be briefly referred to farther on.

How is the Fixation of Nitrogen to be Explained?

Reviewing the whole of the results which have been brought forward, there can be no doubt that the fact of the fixation of free nitrogen in the growth of *Leguminosæ* under the influence

of suitable microbe infection of the soil, and of the resulting nodule-formation on the roots, may be considered as fully established.

Admitting, then, the fact of fixation under the conditions described, the question still remains: How is it to be explained? Unfortunately, there is much yet to learn before a satisfactory answer can be given. Obviously we must know more of the nature and mode of life of the organisms which, in symbiosis with the leguminous plant, bring about the fixation of free nitrogen, before the nature of the action can be understood. As to the mode of life of these bodies, we owe much to the investigations of Marshall Ward, Prazmowski, Beyerinck, and others; but the facts which they have established so far are insufficient to afford an adequate explanation of the phenomena involved.

It is a point of importance that it should be established, as it appears to be, that in the development of the parasite the cortex of the root of the host is penetrated, and so an intimate connection between the two—indeed, a symbiosis—is set up. Then there is abundant evidence that the nodules are very rich in nitrogen. Indeed, in certain stages of their development, their dry substance may contain a much higher percentage of nitrogen than that of any part of the growing plant itself; and, in some cases at any rate, even higher than in that of the highly nitrogenous leguminous seed.

Whence comes this nitrogen? The views of those who have studied the histology and biology of the subject, without reference to quantitative chemical data, do not seem to be very clear or definite on the point. Thus, it has been assumed that the bacteria acquire their nutriment, including their nitrogen, from the protoplasmic cell-contents of the higher plant; and that, on the other hand, the contents of the bacteroid cells are resorbed. In other words, the plant utilises the substance of the bacteroids. It is obvious, however, that, so far as the nitrogen of the bacteria is derived from the plant itself, the latter is not a gainer in a quantitative sense by its resorption.

It has further been assumed that the activity of the process depends on the quantity of the nitrogenous compounds at the disposal of the roots, the tubercles developing unhindered, and becoming large and typical, in a soil rich in nitrogen, but attaining no great size in poorer soils. The source of the nitrogen of the bacteria is here supposed to be combined nitrogen in the soil. The experimental results which have been described clearly show, however, that the nodules may develop very plentifully in a nitrogen-free soil, and that there may, under such

conditions, be great gain of nitrogen if only the soil be suitably infected. Nor would there be any such actual gain of nitrogen in nitrogen-free soils, as there undoubtedly is, if the source of the nitrogen, either of the parasite or of the host, were essentially the supplies of combined nitrogen within the soil.

Further, one assumption is, that the organisms become distributed in the soil both during the life of the host and afterwards, and that the fixation takes place under their agency within the soil itself, rather than in the course of the development of the bacteria in symbiosis with the higher plant. Another assumption is, that the fixation takes place in the soil itself under the influence of microbes existing within it, and that the higher plant assimilates the resulting combined nitrogen. As bearing upon these points, it may be observed that in the experiments with peas in 1888 there was practically no gain of nitrogen within the soil itself, which it may be supposed there would have been if the fixation had taken place within it, and the host had acquired its gain from the compounds there produced. Indeed, the evidence at present at command certainly does not point to the conclusion that the gain of nitrogen by *Leguminosæ* under the influence of microbe infection of the soil, and nodule-formation, is due to fixation by organisms within the soil itself, independently of the symbiosis. It is obvious, too, that, so far as free nitrogen may be fixed by microbes within the soil, independently of connection with a higher plant, the resulting nitrogenous compounds should, directly or indirectly, be available to plants generally, whether leguminous or non-leguminous.

On this point it may be remarked that about thirty years ago Boussingault concluded, from the results of vegetation experiments made in 1858 and 1859 in mixtures of rich soil and sand, that free nitrogen had been fixed within the soil by the agency of mycodermic vegetation, and that the nitrogenous products which remained within it were largely in the form of organic detritus. Subsequently, however, he considered that there was not satisfactory evidence that free nitrogen is fixed within the soil under the influence of the development of lower organisms. It is, nevertheless, of interest to observe that those of his results in 1858 and 1859 which showed any material gain of nitrogen, either in the vegetable matter grown, or in the soil, were obtained with *Leguminosæ*, and that in the case in which there was the greatest gain in the plants themselves, he records that there were numerous tubercles on their roots. In one other case, in which, however, only sand was used as soil, and the gain in the plant was but small, he also observed tubercles on

the roots. In the other cases of gain no mention is made of tubercles, and it may be that the roots were not so examined as to determine whether they existed or not. It is, at any rate, very significant, when viewed in the light of recently acquired knowledge, that in all the cases of gain the plants grown were of the leguminous family, and that in some of them nodules were observed on the roots.

Again, Berthelot's experiments showed fixation of free nitrogen by the agency of microbes within the soil, both in the absence of higher vegetation, and also coincidently with the growth of non-leguminous plants. He further considers that such fixation takes place to an extent which would be an important source of nitrogen to our crops. As referred to above, Boussingault's experiments of 1858 and 1859 showed fixation within the soil which he then attributed to the agency of mycodermic vegetation. The fact of such fixation within the soil, under the influence of lower plants, has also been confirmed by the recent results of some other experimenters. Thus, MM. Schloesing *fils* and Laurent have shown fixation in bare soil, and in soils growing various non-leguminous plants, when certain Lichens and Algæ were developed, but not when their occurrence was prevented. We believe that Hellriegel has also found fixation coincidently with the growth of certain Algæ. Nevertheless, it may be observed, that neither experience in practical agriculture, nor the nitrogen statistics of soils and crops, points to the conclusion that there is gain of nitrogen to any material extent by the fixation of free nitrogen under the agency of microbes within the soil independently of leguminous growth. It was our intention to commence experiments on this subject at Rothamsted in the past year (1891), but we have not yet been able to do so.

In 1888, however, Berthelot made numerous experiments with *Leguminosæ*, and in many of them he found very large gains of nitrogen; indeed, a much higher range of gain than in his other experiments. That there should be large gain under such conditions is quite consistent with the results which have been recorded of the experiments made at Rothamsted in 1888 and 1889 with *Leguminosæ*, and with those previously obtained by Hellriegel and Wilfarth. Further, these results of Berthelot, like those obtained at Rothamsted and by others with leguminous plants, are consistent with well-established facts of agricultural production, and with the nitrogen statistics of soils and crops, and serve with them to aid the solution of long-recognised problems in connection with the growth of leguminous crops.

But, whether or not it may eventually be established that

nitrogen is fixed, to any material extent, by microbes within the soil, independently of leguminous growth, there is evidence that in soils and subsoils containing organic nitrogen, lower organisms may serve the higher plants by taking up or attacking and bringing into a more readily available condition combined nitrogen not otherwise, or only very slowly, available for the higher plants. For example, it is probable that fungi generally derive nitrogen from organic nitrogen; and in the case of those of fairy rings there can be little doubt that they take up from the soil organic nitrogen which is not available to the meadow plants, and that on their decay their nitrogen becomes available to the associated herbage. Then in the case of the fungus mantle, observed by Frank on the roots of certain trees, it may be supposed that the fungus takes up organic nitrogen, and so becomes the medium of the supply of the soil nitrogen to the plant. More pertinent still is the action of the nitrifying organisms in rendering the organic nitrogen of the soil and subsoil available to the higher plants. It may well be supposed, therefore, that there may be other cases in which lower organisms may serve the higher, bringing into a more available condition the combined nitrogen already existing, but in a comparatively inert state, in soils and subsoils.

But to return to the question of the explanation of the undoubted fixation of free nitrogen in the growth of leguminous crops under the influence of suitable microbe infection, and of the development of nodules on the roots of the plants.

As in the exact quantitative series of experiments made at Rothamsted in 1888 and since, some of the results of which have been given, the plants were not taken up until they were nearly ripe, it is obvious that the roots and their nodules could not be examined during growth, but only at the conclusion, when it is to be supposed that the contents of the nodules would be to a great extent exhausted. Another series was, therefore, commenced in 1890, and is still in progress, in which the same four annuals—peas, beans, vetches, and yellow lupins—and the same four plants of longer life—white clover, red clover, sainfoin, and lucerne—were grown in specially-made pits, so arranged that some of the plants of each description could be taken up, and their roots and nodules studied, at successive periods of growth: the annuals at three periods—namely, first when active vegetation was well established, secondly when it was supposed that the point of maximum accumulation had been approximately reached, and thirdly when nearly ripe; and the plants of longer life at four periods—namely, at the end of the first year, and in the second year when active vegetation was re-established, when

the point of maximum accumulation had been reached, and lastly when the seed was nearly ripe. Each of the eight descriptions of plant was grown in sand (with the plant-ash), watered with the extract from a rich soil; also in a mixture of two parts rich garden soil and one part of sand. The pits with their plants were exposed to the open air, but protected from heavy rain.

In the sand the infection was comparatively local and limited, but some of the nodules developed to a great size on the roots of the weak plants so grown. In the rich soil the infection was much more general over the whole area of the roots, the nodules were much more numerous, but generally very much smaller. Eventually the nodules were picked off the roots, counted, weighed, and the dry substance and the nitrogen in them determined.

Taking the peas as typical of the annuals, and the sainfoin of the plants of longer life, the general result was that, at the third period of growth of the peas in sand, the amount of dry matter of the nodules was very much diminished, the percentage of nitrogen in the dry matter was very much reduced, and the actual quantity of nitrogen remaining in the total nodules was also very much reduced. In fact, the nitrogen of the nodules was almost exhausted. The peas grown in rich soil, however, maintained much more vegetative activity at the conclusion, and showed a very great increase in the number of nodules from the first to the third period; and, with this, there was also much more dry substance, and even a greater actual quantity of nitrogen, in the total nodules at the conclusion. Still, as in the peas grown in sand, the percentage of nitrogen in the dry substance of the nodules was very much reduced at the conclusion.

In the case of the plant of longer life, the sainfoin, there was, both in sand and in soil, very great increase in the number of nodules, and in the actual amount of dry substance and of nitrogen in them, as the growth progressed. The percentage of nitrogen in the dry substance of the nodules also showed, even in the sand, comparatively little reduction, and in the soil even an increase. In fact, separate analyses of nodules of different character or in different conditions showed that, whilst some were more or less exhausted and contained a less percentage of nitrogen, others contained a high percentage, and were doubtless new and active.

Thus, the results pointed to the interesting conclusion that, in the case of the annual, when the seed is formed, and the plant more or less exhausted, both the actual amount of nitrogen in the nodules, and its percentage in the dry substance, are greatly reduced; but that, with the plant of longer life, although

the earlier formed nodules become exhausted, others are constantly produced, thus providing for future growth. The results of this new series of experiments, taken together with those of the quantitative series, also serve further to show that there is intimate connection between the gain of nitrogen by *Leguminosæ* and the development of nodules on their roots.

The alternative explanations of the fixation of free nitrogen seem to be—

1. That, under the conditions of the symbiosis, the plant is enabled to fix the free nitrogen of the atmosphere by its leaves.

2. That the nodule-organisms become distributed within the soil, and there fix free nitrogen; the resulting nitrogenous compounds becoming available as a source of nitrogen to the roots of the higher plant.

3. That free nitrogen is fixed in the course of the development of the organisms within the nodules, and that the resulting nitrogenous compounds are absorbed and utilised by the host.

It certainly seems to us that the balance of the evidence at present at command is much in favour of the third mode of explanation. Indeed, there seems little or nothing in the facts to lead to the conclusion that under the influence of the symbiosis the higher plant itself is enabled to fix the free nitrogen of the air by its leaves. Nor does the evidence point to the conclusion that the nodule-bacteria become distributed through the soil and there fix free nitrogen, the compounds of nitrogen there produced being taken up by the higher plant. It seems more consistent, both with the experimental results, and with general views, to suppose that the nodule-bacteria fix free nitrogen within the higher plant, and that the nitrogenous compounds produced are absorbed and utilised by the plant. In other words, there does not seem to be any evidence that the higher chlorophyllous plant itself fixes free nitrogen, or that the fixation takes place within the soil; but it is much more probable that the lower organisms fix the free nitrogen. If this should eventually be established, we have to recognise a new power of living organisms—that of assimilating an elementary substance. But this would only be an extension of the fact that lower organisms are capable of performing assimilation-work which the higher cannot accomplish; whilst it would be a further instance of lower organisms serving the higher. Finally, it may here be observed that Loew has suggested that the vegetable cell, with its active protoplasm, if in an alkaline condition, may fix free nitrogen with the formation of ammonium nitrite. Without passing any judgment on this point, it may be stated that it has frequently been found at Rothamsted that the contents of the

nodules have a weak alkaline reaction when in apparently an active condition—that is whilst still flesh-red and glistening.

It will be seen that the experimental results which have been brought forward constitute only a small proportion of those already obtained, or yet to be obtained, at Rothamsted; and it is hoped that, in the course of the further prosecution of the investigations which have been undertaken, more definite answers will be forthcoming to some of the admittedly still open questions in connection with this interesting and important subject.

Of what Importance to Agriculture is the Newly-recognised Source of Nitrogen to Leguminous Crops?

The question yet remains:—What is the practical importance of the newly-recognised source of nitrogen to the *Leguminosæ*, considered in its bearing on the known facts of agricultural production, and especially on the question of the sources of the nitrogen, not only of leguminous crops themselves, but of crops generally? Unfortunately, as in the matter of the explanation of the action by which the nitrogen is fixed, there is much yet to learn before an adequate answer can be given. Still it is desirable to report progress.

We have said that whilst experience, whether practical or experimental, did not point to an unsolved problem in the matter of the sources of the nitrogen of the agricultural plants of other families, it was quite otherwise so far as those of the *Leguminosæ* were concerned. It is true, that both agricultural investigation, and direct vegetation experiment, have clearly shown that *Leguminosæ* do take up much soil-nitrogen, and, at any rate in great part, as nitrate. But it is admitted that, in the case of some direct experiments bearing on the point, the evidence was not such as to justify the conclusion that the whole of the nitrogen had been so derived; and that hence some other explanation of the large amounts assimilated was needed.

It has been seen that the balance of experimental evidence is against the supposition that the higher plants themselves can assimilate free nitrogen. But, it is now established that, at any rate in the case of some leguminous plants, they gain nitrogen coincidently with the development on their roots of tubercular bodies containing bacteria; and the evidence points to the conclusion that it is the lower organisms, and not the higher plants, that fix free nitrogen.

It has been stated that the characteristic nodules have been

found on the roots of various leguminous plants growing among the mixed herbage of grass-land, and also on those of others growing on arable land, in the ordinary course of agriculture. There can be little doubt that, when such plants are growing in soil and subsoil containing an abundance of combined nitrogen, they will obtain some of their nitrogen from nitrates, or other ready-formed compounds of nitrogen. It has further been suggested, that lower organisms may serve the higher, at any rate in part, by bringing the combined nitrogen existing in the soil and subsoil in a comparatively inert state, into a more readily available condition. An obvious difficulty in the way of the assumption, that much of the greater assimilation of nitrogen by the *Leguminosæ* than by other plants is due to a supply of nitric acid by the nitrification of the combined nitrogen of the subsoil, is that the direct application of nitrates as manure has comparatively little effect on the growth of such plants. In the case of the direct application of nitrates, however, the nitric acid will percolate chiefly as nitrate of soda or nitrate of lime, unaccompanied by the other necessary mineral constituents in an available condition; whereas, in the case of nitric acid being formed as a result of action on the organic nitrogen of the subsoil, it is probable that it will be associated with other constituents, liberated, and so rendered available, at the same time. But, so far as the plants obtain nitrogen derived from the fixation of free nitrogen, the question arises—under what conditions will this supply come the more or the less into play?

In some of the experiments made in pots at Rothamsted, the results of which have been given, there was a less development of nodules on the roots when soil containing an abundance of combined nitrogen was used, than when nitrogen-free sand was employed. But, the less growth, and the less formation of nodules in the rich soil, was supposed to be due to clotting, and therefore to defective porosity, especially after watering. On the other hand, as already said, some experimenters have concluded that the activity of the process depends on the quantity of nitrogenous compounds at the disposal of the roots; the nodules developing unhindered, and becoming large and typical in soils rich in nitrogen, whilst in soils poor in nitrogen they attain no great size.

In the later series of experiments made at Rothamsted, those conducted in pits in the open air, to which brief reference has been made, the general, though not the invariable, result was, however, that there was a much greater number of nodules formed on the roots of the plants growing in rich soil than on those grown in sand. But whilst as a rule the individual, but

much fewer nodules on the roots grown in sand, developed to a much greater size; the much larger number in the soil were very much smaller.

As to the smaller number of nodules formed in sand than in rich soil, the explanation may simply be that, as in the sand the infection was dependent on the additions of rich soil-extract only, the diffusion of the microbes would be only limited, and the infection of the roots therefore only local or accidental; whilst the much greater size of the individual nodules may be due to the want of power in the more weakly plant growing in nitrogen-free soil to resist the free development of the parasite. On the other hand, in the mixture of rich soil and sand, the microbes would probably be distributed throughout it, and the roots accordingly exposed to infection along their whole range. The much less development of the individual but more numerous nodules in the rich soil may be due to one of two very different causes. It may be that although the more vigorous plants grown in the rich soil could not resist the original infection, they were able to resist the further development of the parasite; or, it may be, that with the more vigorous growth the nodules were more rapidly exhausted of their contents to feed the host. It will be obvious that, on the former supposition, some of the nitrogen of the restrictedly developed individual nodules may have been obtained from the nitrogenous matters of the plant itself derived from soil-nitrogen, in which case the gain from fixation would be less than would otherwise be indicated by the great number of nodules produced; and in favour of this supposition, which implies that in the early stages of the infection the bacteria derive nitrogenous nutriment from the stores of the higher plant itself, and only later from the fixation of free nitrogen, is the fact of the observed "nitrogen hunger stage" so characteristic of plants for some time after infection, when growing in nitrogen-free soil, probably indicating that during that period the limited stores of the plant are being drawn upon. On the second supposition, on the other hand—that the smallness of the nodules was due to their rapid exhaustion by the host—it might be that more of the nitrogen of the nodules would be due to fixation, and that hence a larger proportion of the total nitrogen of the plant would be gain attributable to that source.

Obviously more evidence is needed before a decisive opinion can be formed, as to how far fixation of free nitrogen is an essential coincident of nodule-development at all its stages of accumulation, and how far therefore the amount of nodule-formation may be taken as a fair measure of the fixation.

It is to be supposed that when nodules develop abundantly on the roots of leguminous plants growing in soil rich in readily available combined nitrogen, the nitrogen assimilated will be partly due to soil supplies of combined nitrogen, and partly to fixation. That there is gain when red clover, for example, grows luxuriantly on ordinary arable soil, common experience can leave but little doubt. The evidence of fixation is, however, undoubtedly much the clearer in the case of soils poor in nitrogen. Thus, in the cases of the experiments with peas, vetches, and yellow lupins, growing in nitrogen-free but duly infected sand, there being no other supply of combined nitrogen than that in the seed sown, the proportion of the total assimilation due to fixation was undoubtedly very large. It may safely be concluded, indeed, that when luxuriant leguminous crops are obtained on soils characteristically poor in available combined nitrogen, a large proportion of the total nitrogen assimilated will be due to fixation. It is, on the other hand, by no means so clear that, when such plants are grown in soil rich in available combined nitrogen, an abundant development of nodules is to be taken as indicating that a correspondingly great proportion of the total nitrogen assimilated is due to fixation.

There can, however, be little doubt that in the growth in practical agriculture of leguminous crops, such as clover, vetches, peas, beans, sainfoin, lucerne, &c., at any rate some, and in some cases a considerable proportion, of the large amount of nitrogen which they contain, and of the large amount which they frequently leave as nitrogenous residue in the soil for future crops, is due to the fixation of free nitrogen, brought into combination by the agency of lower organisms. Evidence is, however, obviously still wanting, to enable us to judge decisively under what conditions a greater or less proportion of the total nitrogen of the crop will be derived—on the one hand from nitrogen-compounds within the soil, and on the other from fixation.

Incidentally, the question suggests itself—how far the failure of red clover, or of other leguminous crops, may be due to the exhaustion of the organisms necessary for nodule development, and for the coincident fixation of free nitrogen; how far to the exhaustion of combined nitrogen, or of the necessary mineral constituents, in an available condition, within the range of the roots; or, as is sometimes the case, to insect ravages depending on the condition of the soil independently of an otherwise failing condition of the plant.

Assuming it then to be established, that a greater or less, and sometimes a considerable proportion, of the nitrogen of our

leguminous crops will be due to fixation under the conditions supposed, it is obvious that such a fact not only serves to explain the source of the hitherto unaccounted-for amount of the nitrogen of those crops themselves, but that it also affords an explanation of the source of the increased amount of nitrogen which other crops acquire, when they are grown in association, or in alternation, with *Leguminosæ*. Lastly, the fact that, at any rate many leguminous plants, including papilionaceous shrubs and trees, as shown by Nobbe, are susceptible to the symbiosis and under its influence may gain much nitrogen, serves to explain the source of some, at least, of the large amount of combined nitrogen accumulated through ages in our soils and subsoils, and also the comparatively slow exhaustion of their stores of it, by cropping, drainage, and in other ways.

We will, in conclusion, refer to some of the more directly practical aspects of the subject. It may be observed that in Germany, Schultz, of Lupitz, has for some years devoted a considerable area of poor gravelly and sandy soil to the growth of leguminous crops —various clovers, lupins, serradella (*Ornithopus sativus*), &c.—by means of kainit and phosphatic manures, and he has found the land thereby very much enriched for future cereal and other crops. He finds, however, that it is necessary to vary the description of leguminous crop grown. In various parts of Germany, too, the system is gradually extending of growing lupins, serradella, or other leguminous crops, especially on poor sandy soils, with a view to their enrichment in nitrogen. And, on a large estate in Hungary, it was found that the results of the recent investigations indicating the fixation of free nitrogen in the course of the development of leguminous crops were being carefully studied with a view to practical application.

In our own country, Mr. Mason, of Eynsham Hall, Oxfordshire, commenced in 1889 some experiments with various *Leguminosæ* on small plots; and in 1890 a considerable series in specially-built tanks or pits, in which he has grown various leguminous agricultural plants, as well as some leguminous shrubs, with a view to the study of their root and nodule development, and the connection of these with luxuriance of growth, and gain of nitrogen. He has also devoted about 200 acres to the practical application of the recently acquired knowledge in regard to nitrogen fixation. Stated in a few words, his idea is, to reduce his area under roots, and to grow instead mixed crops of *Leguminosæ* — beans, various clovers, &c.—liberally manured with basic slag and kainit, and to convert the produce in the first year into silage, and

in the second into hay. The land is thus occupied for two years, and the assumption is, that in this way highly nitrogenous crops will be obtained with mineral but without any nitrogenous manure, and that the land will be left in high condition so far as nitrogen is concerned for the growth of saleable crops, such as potatoes, or grain, which require nitrogenous manuring. In other words, the plan is, as he puts it, first to grow nitrogen-accumulating crops for home consumption, and afterwards nitrogen-consuming crops for sale. The experiment has been in progress too short a time to judge how far it will be successful in a series of years, or of rotations. It is at any rate pretty certain that, to obtain luxuriant leguminous crops so frequently as the plan supposes, it will be necessary that the description of plant grown should be varied from time to time. It has also yet to be determined, to what extent the nitrogen removed in the leguminous crops and made into silage or hay must be returned to the land in the form of manure; or whether part of the green crop should be consumed on the land, or ploughed in, for the after-growth of the saleable crops.

There is, of course, nothing new in the fact that, after the growth of a leguminous crop, such as red clover for example, the soil is left in a higher condition for the subsequent growth of a grain crop; and that, in fact, the growth of such a leguminous crop is to a great extent equivalent to the application of a nitrogenous manure for the cereal. Indeed, history tells us that more than two thousand years ago it was recognised by the Romans that the occasional growth of plants of the leguminous family had the effect of increasing the growth of the gramineous crops with which they were alternated, and it was stated that the effect was equivalent to that of applying manure. Thus Varro says that, "Certain things are to be sown, not with the hope of any immediate profit being derived from them, but with a view to the following year, because, being ploughed in and then left in the ground, they render the soil afterwards more fruitful;" and the plants used for this purpose were lupins, beans, vetches, and other legumes.

Now, however, that the character of the action is more clearly understood, and it is certain that there is actual gain of nitrogen from sources external to the soil itself, it seems desirable that at any rate tentative trials should be made on different descriptions of soil, with the view of ascertaining whether more advantage cannot be taken of this source of nitrogen than our established practices of rotation at present secure.

The experimental results which have been brought forward clearly establish that there is great gain of nitrogen under

some conditions. It has also been clearly shown, that due infection of the soil and of the plant is an essential to success. The evidence at the same time points to the conclusion that the soil may be duly infected for the growth of one description or some descriptions of plant, but not for some other descriptions. The field experiments on leguminous crops at Rothamsted have further shown, that land which is, so to speak, quite exhausted so far as the growth of one leguminous crop is concerned, may still grow very luxuriant crops of another description of the same family, but of different habits of growth, and especially of different character and range of roots. This result, though undoubtedly more or less due to other causes also, is, nevertheless, in some cases doubtless dependent on the existence, the distribution, and the condition, of the appropriate microbes for the due infection of the different descriptions of plant. In fact, it is pretty certain that success in any system involving a more extended growth of leguminous crops in our rotations will not be attained without having recourse to a considerable variation in the description of leguminous plant grown. Other essential conditions of success will generally be the liberal application of potash and phosphatic manures, and sometimes chalking or liming, for the leguminous crop. Then, the questions would arise—how long the leguminous crop should occupy the land; to what extent it should be consumed on the land, or the manure from its consumption be returned; or, under what conditions the whole, or part, of it should be ploughed in? Lastly, it is probable that more benefit would accrue to the lighter and poorer than to the heavier or richer soils by any such extended growth of leguminous crops.

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ALLOTMENTS,

AND

SMALL HOLDINGS.

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ALLOTMENTS AND SMALL HOLDINGS.

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THE passing of the Allotments Acts of 1887 and of 1890, and of the Small Holdings Act of 1892, is evidence of the public interest taken in recent years in the position and future prospects of the working classes generally, and especially of the agricultural labourer. Stated in a few words, the object of the first two of these measures is to facilitate the acquirement of areas not exceeding one acre, mainly, therefore, for the provision of what may be called garden allotments as distinguished from small agricultural holdings. The object of the more recent measure is, on the other hand, to facilitate the acquirement of areas of more than one, and not exceeding fifty acres, that is, for the acquirement of small farms.

NUMBER OF ALLOTMENTS IN GREAT BRITAIN.

For many years prior to 1887, the system of granting garden allotments to agricultural labourers, and to others of our rural populations, had been established, and it had been gradually extending from year to year. Official returns showing the number of allotments granted from the date of the passing of the Allotments Act in 1887 up to the present time, a period

of rather over five years, have not been published. But such records as are available enable us to form a fairly approximate estimate of the impetus given to the extension of the system by the discussion and by the passing of the Allotments Acts. Thus, the following Table shows, for England, Wales, Scotland, and Great Britain collectively, the number of allotments, not exceeding one acre in area, in 1873, in 1886, and in 1890; the actual increase from 1873 to 1886, and from 1886 to 1890; also the average increase per annum between 1873 and 1886, and between 1886 and 1890. Supposing the returns to relate, as we believe they do, to the middle of the year in each case, the period from 1873 to 1886 will be thirteen years, and that from 1886 to 1890, four years.

TABLE I.—*Number of Allotments, not exceeding* 1 *Acre, in* 1873, 1886, *and* 1890; *also the Total, and the average annual Increase, within each Period.*

	England	Wales	Scotland	Great Britain
Actual Number of Allotments.				
1873	242,542	1,726	2,130	246,398
1886	348,872	4,949	3,974	357,795
1890	441,024	7,562	6,419	455,005
Total Increase in Number.				
1873–1886 (13 years) . .	106,330	3,223	1,844	111,397
1886–1890 (4 years) . .	92,152	2,613	2,445	97,210
Increase in Number per Annum.				
1873–1886 (13 years) . .	8,179	248	142	8,569
1886–1890 (4 years) . .	23,038	653	611	24,302

It may be observed that details not given in the Table show that of the total number of allotments in 1890, in England about 70·5 per cent., in Wales 91·7 per cent., in Scotland 82·4 per cent., and in Great Britain as a whole 71·0 per cent., did not exceed one-quarter of an acre. Further, the figures in the Table show, that whilst the average annual increase in the number of allotments in Great Britain was 8,569 over the thirteen years 1873–1886, it was 24,302 over the four years 1886–1890, or nearly three times as great during the latter period.

Indeed, in reference to these returns, Major Craigie, in his Report dated July 18, 1890,[1] says:

"Making every allowance for the possible imperfections of the earlier figures, it seems impossible to resist the conclusion that a large and important increase has taken place. It is noteworthy that the rate of annual increase in the last four years has been apparently three times as rapid as between 1873 and 1886."

By the Allotments Act of 1890 increased powers were given for the acquirement of allotments; but whether the process has or has not thereby been quickened, there is no published evidence to show. At any rate there is, so far as we are aware, no reason to believe that the rate of increase has been less during the last two than during the preceding four years; and if the increase during the four years 1886–1890 was 97,210, it seems quite reasonable to assume that during the five years from the passing of the Allotments Act of 1887 up to the present time, the increase has considerably exceeded 100,000. Nor is it the least satisfactory element of the result that, out of the very large increase that has undoubtedly taken place, so few (only 2,891) had to be obtained under the provisions of the Acts, and only one compulsorily, as is shown by a return to an order of the House of Commons, issued by the Local Government Board, under date of June 17, 1892 (No. 310). In fact, it would seem that, as is desirable it should be, the influence of the Acts has chiefly been to stimulate voluntary action.

The Return in question shows the number of instances in which Rural Sanitary Authorities, under the provisions of the Allotments Act, 1887, and County Councils, under the provisions of the Allotments Acts of 1887 and 1890, have acquired land for allotments, by compulsory purchase, purchase by agreement, or hire by agreement; it also shows the parish in which the land has been acquired, the acreage, and the number to whom allotments have been let under the Act. It further shows, what Sanitary Authorities have not taken land for allotments, and in each case the reason why they had not done so. It appears that fifty-six Rural Sanitary Authorities have acquired land for allotments under the Allotments Act, 1887; in twelve parishes by purchase under agreement, and in eighty-two by hire under agreement. The total area so acquired was 1,126 acres, and the total number of tenants to whom the allotments had been let was 2,733. Five hundred and eighteen Rural Sanitary Autho-

[1] Return of Allotments and Small Holdings in Great Britain, obtained for the Board of Agriculture by the Inland Revenue Department (C.—6144), 1890.

rities had not acquired land, the reasons assigned being in the majority of cases that allotments had been provided voluntarily by landowners under private arrangements, or that no applications or representations under the Act had been made to them. Four County Councils had also acquired land under the Acts of 1887 and 1890; in only one parish by compulsory purchase, in one by purchase under agreement, and in six by hire under agreement; the total area so acquired being eighty-one acres, and the number of tenants to whom allotments had been let seventy-six. In the case of three parishes, the County Councils had delegated their powers as regards the land acquired by them to the Rural Sanitary Authorities, who had let it to eighty-two tenants. The total acreage acquired under the provisions of the two Acts has been 1,207, and the total number of tenants to whom the land was let was 2,891. No return is given of the acreage or number of allotments acquired independently of the provisions of the Acts, so that the only evidence available for forming a judgment on the point is that given in Table I and in the text; and there is no reason to suppose that the estimate we have given is at all excessive.

There can at any rate be no doubt that there has been a great increase in the acquirement of allotments, directly or indirectly, under the influence of the Allotments Acts of 1887 and 1890; and it is probable that the increase will continue for some time to come. Nor can there be any doubt that such allotments are a very great boon, especially to rural populations. Indeed, the fact of the rapid increase in their number which the figures indicate, is of itself sufficient evidence of the appreciation of them by those whose position they are intended to improve. It is another matter, however, whether the sanguine anticipations of those who have so strongly urged the importance of providing by enactment facilities for the acquirement, not only of allotments but of small holdings, will be realised. As every year sees an increasing number of the rural populations flocking into our towns and cities, it is, perhaps, not unnatural that the urban populations should ask why those who have been born upon the land should not be able to earn a living upon it. It will probably be admitted, on all hands, that the extension of the garden allotments system can do little of itself to stem the exodus of the populations of our villages and their accumulation in our towns. But it seems to be assumed that if existing farmers cannot or will not employ more men, the proper remedy is to establish small farms throughout the country by the aid of public funds, to be taken up, either with a view to eventual ownership, or in some cases as tenants only,

by labourers who would thus be rendered independent of weekly wages, or by others who would thus acquire an interest in the land, and so have an inducement to remain upon it. Such a subject is obviously one of great national importance, and it certainly is desirable that it should be freely and fairly discussed on its merits, without reference to party politics.

Number and Acreage of Small Holdings in Great Britain.

It is well known that within the present century there has been a great reduction in the number both of owners and of occupiers of farms not exceeding 50 acres in area, such as it seems to be the object of the promoters of the Small Holdings Act of 1892 greatly to increase. We are not able to adduce comparative statistics for different periods, showing the decline in the number and acreage of such holdings. Such evidence as is at command seems to indicate that the greatest decline was early in the century, and that it gradually lessened towards the middle. It would appear, however, that there has been a slight tendency to increase from about the commencement of the fourth quarter of the century up to the present time. Thus, in Major Craigie's Report on the Return of Allotments and Small Holdings in Great Britain obtained for the Board of Agriculture by the Inland Revenue Department—and issued in 1890 (C.—6144)—he gives the following comparative statement of the total number of holdings in Great Britain, not exceeding 50 acres, in 1875, 1880, 1885, and 1889:

Year	Small holdings
1875	389,941
1880	391,429
1885	392,203
1889	409,422

It is admitted that, as a rule, the later returns are more correct than the earlier; and the increase shown from 1875 tc 1880, and that from 1880 to 1885, are so small, that they might well be explained by greater exactitude in the returns. But the increase from 1885 to 1889 amounts to 17,219, or to more than 4 per cent., and this seems too much to attribute to error in the earlier record. If, however, we exclude the holdings of less area than 1 acre, some of which it is supposed are also included in the Returns of Allotments, the increase in the number from 1 acre to 50 acres would only be about 12,000;

more than two-thirds of which would only range from 1 to 5 acres in area.

It would of course be desirable, were it possible, accurately to compare both the number and the area of holdings of various sizes at different periods, going back much earlier than the dates referred to in the summary given above. In default of reliable data of this kind, it will nevertheless be of interest to direct attention to the returns for 1885, which are more complete than those for any other period. Thus, for that year, there are given—for England, Wales, Scotland, and Great Britain as a whole—the actual number, the proportional number per cent., the acreage or aggregate area, and the average size of holdings, from ¼ to 1 acre, from 1 to 5, from 5 to 20, from 20 to 50, from 50 to 100, from 100 to 300, from 300 to 500, from 500 to 1,000, and from 1,000 acres upwards. There are also given, the number and the acreage of the respective holdings, which are wholly permanent pasture, wholly arable, and partly pasture and partly arable. Of these voluminous records,[1] Tables II, III, and IV, which follow, are summaries; and they give the various particulars for holdings from 1 acre to 50 acres, and above 50 acres, respectively.

It will be observed that holdings from ¼ to 1 acre are not included in the results given in the Tables, and this should be borne in mind in reading the comments thereon. As indicated above, it is probable that some of the holdings from ¼ to 1 acre have also been included in the returns of allotments; and although the number of these smaller holdings is not immaterial, the area is quite insignificant. Thus, in Great Britain the number of such holdings is 23,512, corresponding to about 4¼ per cent. of the whole; but their area is only 11,195 acres, corresponding to only 0·034 per cent. of the total recorded agricultural area. It should be further borne in mind, in judging of the results, that a considerable number of the recorded holdings, and especially of the smaller ones, will consist of areas attached to residences, for ornament or convenience, rather than as a means of livelihood to the holder; also of areas held by persons not entirely dependent on the land for their livelihood. Then, again, especially in Wales and in Scotland, there is a not inconsiderable amount of rough or hill grazing not included in the returns of agricultural area.

The upper division of Table II shows that in each of the

[1] Returns of the number of allotments detached from and attached to cottages and of agricultural holdings in Great Britain, obtained for the Agricultural Department, Privy Council Office, by the Inland Revenue Department (C.—4848), 1886.

TABLE II.—*Actual Number, and Per Cent. in the total Number; aggregate Acreage, and Per Cent. in the total Area; also average Size of Holdings, from 1 to 50 Acres, and above 50 Acres, respectively.*

1885.

Size of holdings	England	Wales	Scotland	Great Britain
Actual Number of Holdings.				
From 1 to 50 acres . .	No. 273,660	No. 40,759	No. 54,272	No. 368,691
Above 50 acres . . .	120,221	18,348	25,083	163,652
Total . . .	393,881	59,107	79,355	532,343
Per cent. in total Number of Holdings.				
From 1 to 50 acres . .	Per cent. 69·48	Per cent. 68·96	Per cent. 68·40	Per cent. 69·26
Above 50 acres . . .	30·52	31·04	31·60	30·74
Total . . .	100·00	100·00	100·00	100·00
Aggregate Acreage of Holdings.				
From 1 to 50 acres . .	Acres 3,548,559	Acres 655,183	Acres 667,289	Acres 4,871,031
Above 50 acres . . .	21,332,992	2,162,834	4,180,200	27,676,026
Total . . .	24,881,551	2,818,017	4,847,489	32,547,057
Per cent. in total Area.				
From 1 to 50 acres . .	Per cent. 14·26	Per cent. 23·25	Per cent. 13·76	Per cent. 14·97
Above 50 acres . . .	85·74	76·75	86·24	85·03
Total . . .	100·00	100·00	100·00	100·00
Average Size of Holdings.				
From 1 to 50 acres . .	Acres 13	Acres 16¼	Acres 12¼	Acres 13¼
Above 50 acres . . .	177⅓	117⅞	166⅛	169⅝
Average of all	63⅛	47⅛	61⅛	61⅛

three divisions of Great Britain the number of holdings from 1 acre to 50 acres is more than twice as great as that of those above 50 acres; indeed, the second division shows that not far short of 70 per cent. of the total number of holdings range from 1 to 50 acres. When we come to consider the question of

aggregate acreage, however, the result is very different. The figures in the third and fourth divisions of the Table show that the aggregate area of the much greater number of the smaller holdings is very much less than that of the much fewer larger ones. In fact, the figures for Great Britain as a whole show that not quite 15 per cent. of the total returned agricultural area (excluding holdings under 1 acre) is devoted to holdings from 1 to 50 acres. Wales, with its very small total agricultural area, shows, however, more than 23 per cent. comprised in the smaller holdings; whilst Scotland with its larger, and England with its very much larger, total area, show an average of only about 14 per cent. in holdings from 1 to 50 acres. Again, the bottom division of the table shows that the size of the holdings in Great Britain from 1 to 50 acres averages only 13¼ acres, and that of those above 50 acres a little over 169 acres, whilst the average of all is about 61 acres. The details show that the average size of the smaller and of the larger holdings respectively, is approximately the same in England, Scotland, and Great Britain as a whole; whilst in Wales that of the smaller is greater, and that of the larger is less, than in the other divisions of the country. Details not here given further show that more than two-fifths of the total agricultural area of Great Britain are comprised in holdings from 100 to 300 acres, and nearly three-fourths in those from 50 to 500 acres.

Table III, p. 11, shows the number, and the proportion, of the smaller and of the larger holdings respectively, which are wholly permanent pasture, wholly arable, or partly permanent pasture and partly arable.

It is seen that of the total number of holdings from 1 to 50 acres in England, nearly half (48·2 per cent.) are wholly permanent pasture, next come those that are mixed pasture and arable (35·63 per cent.), and in much smaller number those that are arable only (16·17 per cent.). In Wales, as would be expected, the proportion of those wholly permanent pasture to those wholly arable is much greater, whilst those in mixed pasture and arable number considerably more than the other two put together. In Scotland, on the other hand, the larger number of the small holdings are entirely arable (51·44 per cent.); next come those that are mixed pasture and arable (39·43 per cent.); and there is a very small number wholly permanent pasture (9·13 per cent.). Lastly, in Great Britain as a whole, of the total number of the smaller holdings, 41·28 per cent. are in permanent pasture, 20·23 per cent. arable, and 38·49 per cent. in mixed pasture and arable.

Next, comparing the number and the general agricultural

TABLE III.—*Actual Number, and Percentage in the Total Number, of Holdings from 1 to 50 acres, and above 50 acres respectively, which are wholly permanent pasture, wholly arable, or mixed pasture and arable; also the Percentage of the Total Number in pasture, in arable, &c., comprised in the smaller and in the larger Holdings respectively.* 1885.

Size of holdings	Actual number of holdings				Percentage of the total number of the smaller, and of the larger holdings, in pasture, arable, &c.			Percentage of the total number in pasture, in arable, &c., respectively, in the smaller and in the larger holdings			
	Permanent pasture	Arable	Mixed pasture and arable	Total	Permanent pasture	Arable	Mixed pasture and arable	Permanent pasture	Arable	Mixed pasture and arable	Total
England.											
Acres	No.	No.	No.	No.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
1—50 . . .	131,917	44,238	97,505	273,660	48·20	16·17	35·63	92·70	93·85	47·69	69·48
Above 50 . .	10,380	2,897	106,944	120,221	8·63	2·41	88·96	7·30	6·15	52·31	30·52
Total . .	142,297	47,135	204,449	393,881	36·13	11·97	51·90	100·00	100·00	100·00	100·00
Wales.[1]											
1—50 . . .	15,316	2,439	23,004	40,759	37·58	5·98	56·44	95·43	92·00	56·94	68·95
Above 50 . .	773	212	17,403	18,348	3·99	1·16	94·85	4·57	8·00	43·06	31·05
Total . .	16,049	2,651	40,407	59,107	27·15	4·49	68·36	100·00	100·00	100·00	100·00
Scotland.[1]											
1—50 . . .	4,955	27,919	21,398	54,272	9·13	51·44	39·43	85·55	72·93	60·66	68·40
Above 50 . .	837	10,364	13,882	25,083	3·34	41·32	55·34	14·45	27·07	39·34	31·60
Total . .	5,792	38,283	35,280	79,355	7·30	48·24	44·46	100·00	100·00	100·00	100·00
Great Britain.											
1—50 . . .	152,188	74,596	141,907	368,691	41·28	20·23	38·49	92·72	84·70	50·66	69·26
Above 50 . .	11,950	13,473	138,229	163,652	7·30	8·23	84·47	7·28	15·30	49·34	30·74
* Total . .	164,138	88,069	280,136	532,343	30·83	16·55	52·62	100·00	100·00	100·00	100·00

[1] Especially in Wales and in Scotland, there is a not inconsiderable amount of rough or hill pasture, not included in the returns of either permanent pasture or total agricultural area; and in Scotland rotation grasses are left down for more than one year, and their area is, of course, included as "arable."

conditions of the holdings above 50 acres in area, it is seen that in England nearly 89 per cent. of the whole are mixed permanent pasture and arable; only 8·63 per cent. exclusively permanent pasture, and only 2·41 per cent. exclusively arable. In Wales those in mixed permanent pasture and arable are nearly 95 per cent. of the whole, those exclusively permanent pasture constitute scarcely 4 per cent., and those exclusively arable little more than 1 per cent. In Scotland, on the other hand, only 55·34 per cent. of the total number are mixed, 41·32 per cent. are exclusively arable, and only 3·34 per cent. exclusively permanent pasture. In Great Britain as a whole, 84·47 per cent. of the total number of the larger holdings are mixed permanent pasture and arable, 7·30 per cent. exclusively pasture, and 8·23 per cent. exclusively arable.

Lastly, comparing the agricultural conditions of the holdings from 1 to 50 acres with those above 50 acres, as shown in the last four columns of the Table (p. 11), it is seen that in each division of the country a very much larger proportion of the smaller than of the larger holdings is either exclusively pasture or exclusively arable. Indeed, there are very few of the larger holdings that are exclusively either the one or the other. On the other hand, among the holdings that are mixed permanent pasture and arable, in England rather more than half the total number (52·31 per cent.) are in the larger holdings, in Wales less than half (43·06 per cent.), and in Scotland less than 40 (39·34) per cent. are in the larger holdings; and in Great Britain collectively, about an equal number (50·66 and 49·34 per cent.) are in the smaller and in the larger holdings respectively.

The next Table (IV), p. 13, which compares, not the number but the aggregate area, of the smaller and of the larger holdings, in permanent pasture, or arable land, in the different divisions of the country, is in some respects of more interest.

It has already been shown in Table II, that in England and Scotland about 14 per cent., in Wales about 23 per cent., and in Great Britain about 15 per cent., of the total agricultural area (excluding holdings under 1 acre) are devoted to holdings from 1 to 50 acres. Table IV, now under consideration, shows the aggregate area, and the proportion of the whole, under permanent pasture and arable respectively, in the smaller and in the larger holdings. In Great Britain as a whole, of the about 15 per cent. of the total area which is devoted to the smaller holdings, 61·2 per cent. is permanent pasture and 38·8 per cent. arable. Of the remaining, about 85 per cent. of the total area comprising the larger holdings, scarcely 44·8 per cent. is permanent pasture, and 55·2 per cent. is arable. In other words,

TABLE IV.—*Aggregate Area, and Percentage in the Total Area, of Holdings from 1 to 50 acres, and above 50 acres respectively, in permanent pasture, and in arable: also the Percentage of the Total Area in pasture, and of the total arable area, comprised in the smaller and in the larger Holdings respectively.* 1885.

Size of holdings	Aggregate area			Percentage of the total area in the smaller and in the larger holdings respectively, in pasture, and in arable		Percentage of the total pasture, and of the total arable area respectively, in the smaller and in the larger holdings		
	Permanent pasture	Arable	Total	Permanent pasture	Arable	Permanent pasture	Arable	Total
			England.					
Acres	Acres	Acres	Acres	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
1—50	2,356,168	1,192,391	3,548,559	66·40	33·60	19·23	9·44	14·26
Above 50 . . .	9,893,281	11,439,711	21,332,992	46·38	53·62	80·77	90·56	85·74
Total	12,249,449	12,632,102	24,881,551	49·23	50·77	100·00	100·00	100·00
			Wales.[1]					
1—50	457,351	197,832	655,183	69·81	30·19	24·02	21·65	23·25
Above 50 . . .	1,446,894	715,940	2,162,834	66·90	33·10	75·98	78·35	76·75
Total	1,904,245	913,772	2,818,017	67·57	32·43	100·00	100·00	100·00
			Scotland.[1]					
1—50	167,636	499,653	667,289	25·12	74.88	13·68	13·79	13·76
Above 50 . . .	1,058,384	3,121,816	4,180,200	25·32	74·68	86·32	86·21	86·24
Total	1,226,020	3,621,469	4,847,489	25·29	74·71	100·00	100·00	100·00
			Great Britain.					
1—50	2,981,155	1,889,876	4,871,031	61·20	38·80	19·38	11·01	14·97
Above 50 . . .	12,398,559	15,277,467	27,676,026	44·80	55·20	80·62	88·99	85·03
Total	15,379,714	17,167,343	32,547,057	47·25	52·75	100·00	100·00	100·00

[1] Especially in Wales and in Scotland, there is a not inconsiderable amount of rough or hill pasture, not included in the returns of either permanent pasture or total agricultural area; and in Scotland rotation grasses are left down for more than one year, and their area is, of course, included as "arable."

there is a much larger proportion of permanent pasture than of arable land in the smaller holdings, and a larger proportion of arable than of permanent pasture in the larger holdings.

In England and in Wales there is a larger proportion, but in Scotland a very much smaller proportion, of the total area of the small holdings in permanent pasture than in Great Britain as a whole. Of the total area of the larger holdings, on the other hand, in England 46·38 per cent., in Wales 66·9 per cent., and in Scotland only 25·32 per cent., are permanent pasture; and it is remarkable that in Scotland the proportion of pasture to arable is almost exactly the same in the smaller and in the larger holdings.

Again, in England, of the total area under permanent pasture 19·23 per cent. is in the smaller, and 80·77 in the larger holdings; and of the total arable area, only 9·44 per cent. is in the smaller, and 90·56 per cent. in the larger holdings. In Wales, of the total area under permanent pasture, 24·02 per cent. is in the smaller, and 75·98 in the larger holdings; and of the total arable area, 21·65 per cent. is in the smaller, and 78·35 per cent. in the larger holdings. In Scotland, 13·68 per cent. of the total permanent pasture area is in the smaller, and 86·32 per cent. in the larger holdings; and of the total arable area almost exactly the same proportions as of the total permanent pasture, namely, 13·79 per cent., is in the smaller, and 86·21 per cent. in the larger holdings. Lastly, in Great Britain as a whole, of the total pasture area, 19·38 per cent., or nearly one-fifth, is in the smaller, and 80·62 per cent., or more than four-fifths, are in the larger holdings; whilst, of the total arable area, only about 11 per cent. is in the smaller and nearly 89 per cent. in the larger holdings.[1]

Upon the whole, then, excepting in Scotland, a very much larger proportion of the area of the smaller holdings is permanent pasture than arable. On the other hand, excepting in the small total area comprised in Wales, a larger proportion of the area of the larger holdings is arable than permanent pasture; and in Scotland this is pre-eminently the case not only in the larger but also in the smaller holdings (see footnote to Table IV, p. 13).

Such is, in outline, a statistical view of the present position of allotments, and of small holdings, in the country generally. It is proposed, in the next place, to illustrate the working of the

[1] Details not given in the Tables show that of the total number of 368,691 holdings from 1 to 50 acres in Great Britain, only 84,149 have an area of from 20 to 50 acres. It may safely be concluded, therefore, that considerably less than this smaller number are held by persons depending entirely on the land for their livelihood. It may further be observed that the areas from 20 to 50 acres comprise a larger proportion of arable than do the smaller ones.

allotment system, by reference to actual experience in a particular case; and then to consider, from an agricultural and economic point of view, what conditions seem essential to the success of small holdings, and whether they prevail to such an extent in Great Britain as to justify the expectation that the establishment of large numbers of them throughout the country will bring about the beneficial results, and especially the stemming of the migration of the population from the country to the towns, which seem to be anticipated by those who advocate a considerable extension of them.

The Rothamsted Allotments.

It is now about forty years since from eight to ten acres, and a few years later about an equal area, were set apart on the Rothamsted Estate as garden allotments, for the most part of one-eighth of an acre each; some, however, being less; the whole number of tenants amounting to between 160 and 170. In the midst of the allotment ground a club-house was built for the members, where they could have their beer and smoke their pipes independently of the public-house. The management of the gardens and of the club is in the hands of a committee of twelve of the members, who are elected annually.[1] Many of these allotments are held by agricultural and other labourers, and it is the general opinion that one-eighth of an acre is quite as much as a man depending on weekly wages can properly cultivate. In fact, whilst no demand has been made for larger garden allotments, requests have occasionally been made for smaller ones, on account of the smallness of the family, or the age of the tenant.

In 1883 nearly 9 acres, and in 1885 about 20 acres, or in all nearly 29 acres, were devoted to allotments in another part of the parish. Of these, 112 are of one-eighth of an acre or less, and 25 are of larger area. There are 23 allotments ranging from a quarter of an acre to an acre and a half, and these are, for the most part, held by persons of the most varied occupations, namely: two carpenters, two publicans, a blacksmith, two carters, a dealer, a butcher, a coal-dealer, a navvy, a platelayer, a market gardener, a groom and gardener, a pensioner, a bricklayer, a shoemaker, and a general labourer. There are also five agricultural labourers, two of whom have, however, joined with others.

In 1890, a notice was put up in the club-room that about 6 acres adjoining the original garden allotments would be let

[1] See Jour. Roy. Ag. Soc. Vol. XIII. (1877), p. 387, "The Rothamsted Allotment Club." By J. Bennet Lawes.

in plots of one acre each, at the ordinary agricultural rent of the land; but not a single agricultural labourer became an applicant for one of these lots.

Lastly, in the present year, 1892, about 5 acres more have been added; and they have been divided into two allotments of 1 acre each, 11 of $\frac{1}{8}$ of an acre, 6 between $\frac{1}{8}$ and $\frac{1}{16}$, and 14 of $\frac{1}{16}$ of an acre. The two 1-acre plots are respectively occupied by a blacksmith and a carpenter; and of the remaining 31 of $\frac{1}{8}$ of an acre or less, only three by agricultural labourers, the remainder being held by persons of very various occupations. It may be said that the demand for mere garden allotments is for the present satisfied; but there still remains a desire for more 1-acre plots.

Of the total number of 334 allotments, about 300 are garden allotments of one-eighth of an acre or less, and it is among the tenants of these that almost the whole of the agricultural labourers are to be found; whilst the majority of the holders of the larger allotments are persons whose earnings and general position are much above those of the labourer, some of them owning the houses in which they live, and having horses or other live-stock.

The general result is then, that, with the soil and climate such as they are in this locality, the demand for anything more than garden allotments has not come from those engaged in agricultural pursuits. The problem of the advancement of the agricultural labourer by giving him a more direct interest in the land he cultivates is, therefore, in no way advanced towards a solution by the facts above stated. Long before the cry of "Three acres and a cow" was invented, the possibility or desirability of furnishing the labourer with the means of keeping a cow was carefully considered at Rothamsted; but the idea was eventually abandoned, as it was thought that the soil and climate were not sufficiently suitable for pasture, especially in dry summers; and that, under such circumstances, the keep of a cow would be very expensive.

Conditions Essential to the Success of Small Holdings.

It is one thing to provide the agricultural labourer with sufficient garden ground to occupy his spare time, and provide his family with vegetables, or to provide the small tradesman of more spare means and time, and who does not derive his livelihood from the land, with a somewhat larger area to enable him to add a little to his income; and it is quite another to establish tenants or proprietors of small holdings, who are supposed not to receive wages, or to have other occupations, but to derive the whole of their livelihood from the land. It is

alleged, however, that with such a system there would be created an incentive to the rural populations to remain on the land, instead of migrating to the towns, or emigrating to our colonies or elsewhere.

It happens that for many years past there has been an excellent school in our village, with the result that many of the sons of the labourers look with contempt at the occupation of their fathers. They easily obtain much better wages on the railways or in the towns than they can get on the land; and, as a rule, they succeed exceedingly well if they are moderately intelligent, and also industrious and steady. It seems to be assumed, however, especially by those not acquainted with practical agriculture, that if a sufficient quantity of land can be obtained at a moderate price, and small farms established on it, the flow of the rural populations into the towns will be arrested; and some, indeed, are so sanguine in the matter, that they think it is desirable that the land should be taken compulsorily, in order to secure so important a result. It is not without interest, therefore, to consider what are the probabilities that the nation, or the ratepayers, would obtain an adequate return in the shape of interest, if land were acquired at its ordinary agricultural value and devoted to such a purpose.

There is some fairly good agricultural land in this parish (Harpenden), which might, perhaps, be obtained at the rate of 30*l.* per acre. Opinions may differ as to how many acres would be required to support a man, his wife, and family; but if we assume the land to be arable, and that ordinary farm crops are to be grown upon it, it is probable that, with the very low saleable value of grain, not less than forty or fifty acres would be required to enable the holder and his family to make a living in this way. The purchase money of, say, fifty acres, at 30*l.* per acre, would be 1,500*l.* A house, stable for two horses, cow-house, some open shedding, a yard walled in, all the necessary roads and fencing, and, by way of equipment of the farm, a pair of horses, one or two cows, a few sheep and pigs, and the necessary implements, would together not cost less than 700*l.* or 800*l.* So far, then, the outlay would probably be about 2,250*l.*

When a man is set up in a shop he begins at once to earn a living, but not so the farmer. Supposing he enters upon his farm at Michaelmas, he must have the means of living, keeping his stock, and paying any other expenses, until nearly the next Michaelmas; and for this at least 1*l.* 15*s.* per week must be allowed, making altogether 91*l.* Further, for the same reason, that there would be little or no produce to sell during the first year, anything in the shape of interest or annual instalment, which can hardly be put down at less than 20*s.* per acre, as

well as tithe rent-charge and rates, at, say, 8*s.* per acre, making together 70*l.*, would probably have to be placed to capital account, which, for the first year, would therefore stand at 2,411*l.*[1]

According to the provisions of the Small Holdings Act (1892), the money required will not be available at lower interest than 3½ per cent. At this rate the interest on the above sum would amount to rather over 75*l.* per annum. This amount would certainly rather heavily handicap the small farmer. Nor does the transaction promise to be a very satisfactory one for the ratepayers, who will be responsible for the money in the last resort. Then, on the assumption that the tenant is to become the owner, there will be a further annual charge beyond that of mere rent, for a shorter or longer period of years, according to the amount which he is able to pay off independently in the meantime.

Such, then, are some of the difficulties which will have to be encountered in any attempt to create a class of tenants, or of owners, of small farms. The foregoing calculations have, however, reference only to the establishment of small arable, or what may be termed rotation, or grain and meat farms; and when we consider that, comparing the first five of the last twenty-five years (1867–1891), with the last five, the average price of wheat per quarter has gone down from 56*s.* to 32*s.* 7*d.*, that of barley from 38*s.* 8*d.* to 27*s.* 2*d.*, and that of oats from 25*s.* 8*d.* to 17*s.* 10*d.*, the prospect is not very promising for the small farmer, who will have to produce his grain, not only in competition with foreign countries, but with the farmers of his own country who hold land enough to take full advantage of all labour-saving appliances. He will also have to compete in his own markets with the foreign produce of meat, the imports of which, live and dead, have enormously increased in recent years.

Whilst, then, the outlook for the small grain and meat farmer must be considered very discouraging, the question still remains, whether small tenancies or small holdings would not be of advantage, both to those who cultivate them and to the nation at large, if the land were devoted mainly to the production of milk, butter, and cheese, poultry and eggs, vegetables and fruit. In favour of such a system it is pointed out how large is the annual value of our imports of such smaller articles

[1] With reference to the above estimate of probable cost, the following statement, which was lately published, may be quoted: "A Freehold Farm in the parish of Whaplode, belonging to Mr. Robert Coupland, comprising a small farmhouse, with barn and bullock hovel and four pieces of excellent arable land adjoining, containing altogether 53 acres 0 roods 38 poles (more or less), has been sold for 2,390*l.* to Dr. Cotton, of London."

of production. Thus, the value of the following articles imported into the United Kingdom in 1890 was—

	£
Poultry and game	497,857
Eggs	3,428,806
Butter	10,598,848
Cheese	4,975,134
	£19,500,645
Potatoes	714,257
Onions	724,020
Other vegetables	773,590
Apples	786,072
Other raw fruit	1,806,811
	£4,804,750
	£19,500,645
	£24,305,395

In 1890, therefore, the value of the imports into the United Kingdom, of poultry and game, eggs, butter, and cheese, was 19,500,645*l.*, and that of vegetables and fruit was 4,804,750*l.*, making together about 24⅓ million pounds.

It is sometimes said that all these at any rate, if not all the grain and meat required for consumption, should be produced at home. In reference to the argument that we should produce more of the staple agricultural products also, it is to be borne in mind that we do at present produce more per acre of both wheat and barley than any other country; more of oats than any excepting one or two of comparatively small area under the crop; also more of potatoes, and a greater weight of live-stock for a given area, than any other country the statistics of whose production are known. If, under our existing system of agriculture, we accomplish this, it is natural to suppose that there is something in our soil and climate, as well as in the habits of the people, compared with those of the countries supplying us with so much of the smaller articles above referred to, to account for the fact that they are able to compete with us in our own markets in the supply of those productions. In most, if not in all continental countries, the success of small holdings depends very materially on whether or not the soil and the climate are suited for the production of what may be called industrial crops, such as tobacco, hops, sugar-beet, colza, flax, hemp, and grapes, also other fruit and vegetables. Where these conditions do not exist, and ordinary rotation crops are relied upon, and especially where, with this, the land is much subdivided, the condition of the cultivators is such as would not be tolerated in this country.

Belgium is frequently quoted as a model for ourselves in the

matter of small holdings, and the production of the smaller articles of comparatively high value. Belgium and England are, indeed, in some particulars, well suited for comparison, but in others for contrast rather than comparison. Thus, Belgium and England have each a much greater population for a given cultivated area than any other European country; and the number is very nearly the same for a given area in the two countries. But, whilst England produces more grain, more potatoes, and a greater weight of live-stock, per acre, than Belgium, Belgium, on the other hand, gives a greater proportion of dairy produce, poultry and eggs, and fruit and vegetables; and small holdings are very characteristic of the portions of the country yielding these results. By far the greater number of the small holdings are in the light land districts, and in those districts the cultivators are, as a rule, not the proprietors. There are, however, some small farms in the heavier land districts, and here the cultivators are frequently the owners also. It is admitted that the larger farms yield a greater produce per acre of ordinary farm crops and stock than the smaller ones.

Owing to the peculiarities of the soil and climate, especially of the great light land district where the small holdings prevail, a very characteristic practice is the growth of two crops in one year. Thus, with a light soil, high summer temperature, long days, and an open autumn, the growth of what we call "catch crops" is a very prominent feature. Under these conditions the harvest is early, and, after the removal of the grain, a catch crop can be taken. After rye, turnips are almost invariably taken; turnips or spurrey after other corn crops, or carrots are sown in the wheat or flax. Indeed, it is stated that, owing to the adaptation of soil and climate, one-eighth of the whole of the cultivated land grows two crops a year. It is fully recognised in Belgium by those officially acquainted with the subject, that the success of the small holdings depends very much on the facts,—that the soil is easily worked, that the soil and climate are such as to favour the practice of catch cropping, and that they are also favourable for the production of industrial crops, dairy produce, poultry and eggs, fruit and vegetables; whilst the dense population generally, and the large number of towns, afford convenient markets for the produce, and for the return of town manures.

Of course, catch crops are not unknown in our own country, but it is only in some of our earliest districts that they could be relied upon. This fact is of itself evidence of a very material difference in the mutual relations of soil and climate in Great Britain and in the small holding districts of Belgium; and this difference would be very materially to the disadvantage of Great Britain in competition, not only with Belgium, but

with other countries, in the production of some of the smaller articles of high value which have been referred to.

In illustration of some of the characteristics of the farming of small holdings under suitable conditions, some facts may be given from a Report published in the Journal of the Royal Agricultural Society,[1] of a journey undertaken at the request of the Council of the Society, by the late Dr. Voelcker and Mr. Jenkins, the late secretary, to study the agriculture of Belgium. In the course of their description of a successful farm of ten acres, supporting three or four persons, they quote from the accounts of one year, which showed that besides wheat, dairy and garden produce, &c., an acre of colza sold for 21*l.* 10*s.*, a tenth of an acre of flax for 5*l.* (equal to 50*l.* per acre), and a quarter of an acre of tobacco for 16*l.* (equal to 64*l.* per acre). It will be observed that two out of the three of these are industrial crops, upon which much labour is expended after they are removed from the land.

Then, as examples of small holdings in France, Consul Pauncefote, referring to the district of Nantes, says that the position of peasant proprietors is a miserable one, and that the system of peasant proprietorship is not a good one for getting the value out of the land, and, except under special circumstances, is a very bad one for the proprietor himself from the point of view of worldly prosperity. He says:

"This class never did and never can live by farming as we understand it in England, and the mistake of supposing that they were doing so has arisen from the circumstance that a large population certainly was supported for many years on small patches of land; but they were manufacturers of wine and brandy, not farmers. A man saved up money and bought a piece of ground planted with vines, and employed his labour and that of his family in the threefold occupation of caring for them, making wine, and distilling brandy; and it was the profit from these three operations, two of which are industrial, not agricultural, which enabled him to make a living. The vines have failed, and the towns are filled with those peasant proprietors looking for work, who, instead of having been kept in the country by making them owners, have been ruined by it, and prefer anything else to going back to it. And not only have these people been ruined themselves, but as most of them became owners through the facilities offered by some of the great financial societies in Paris, these establishments have suffered great losses."

Again, the British Consul-General at Havre, in his last report, says:

"The farms are what would be called in England quite small, and the tenants or owners, as the case may be, work excessively hard on them. I think their faces would be a study were they to be told that they were not to work more than eight hours a day on the land. The great advantage the small owner or proprietor has in France is in the difference of climate which favours the growth, &c., of various articles and small products which do not do so well with us, and sufficient allowance is not made for this when comparison is

[1] Vol. VI. (1870), pp. 1–86.

drawn between the two countries, France and England, and their respective systems."

There are, however, exceptions to such conditions; as, for example, in the Beet-root sugar districts of France, chiefly in the north. There are there hundreds of thousands of acres of sugar-beet, largely grown by the small farmers, who are materially aided in working capital, and consequently in the production and use of manure, by their connection with the sugar industry; and one result of this is that they, as a rule, produce very much greater crops of wheat than the average of the country at large; indeed, on the average, only a few bushels less than the yield of the United Kingdom. But it must not be forgotten that these results have been obtained under the influence of bounties on sugar, and a price of wheat artificially raised by import duties.

If, however, small holdings are to be established to any considerable extent in Great Britain, there can be no doubt that success must be looked for, not in ordinary rotation farming, but in an extension of dairy-farming where the soil and climate are suitable, in an increased production of poultry and eggs, and also, where the soil and climate are suitable, on what is in reality market gardening rather than agriculture. So far as fruit and vegetables are concerned, however, it is to be borne in mind that the high value of the imports of these articles depends largely on earliness and quality, in which particulars it is only in a few limited districts that we could hope successfully to compete with the countries which now supply us with so much of such produce.

Nor can there be any doubt that, so far as land had to be acquired for such purposes as these, as distinguished from ordinary agriculture, such land would, both from its locality and its quality, command a much higher value in the market than has been assumed in the illustration of the requirements of a farm of fifty acres devoted to the ordinary agriculture of the district in which it is situated. On the other hand, a smaller area would, if the soil and climate were suitable, be sufficient to support the holder and his family; but, at the same time, the outlay per acre would be considerably greater. Upon the whole, therefore, although there is certainly much more promise in this direction than in the case of small farms devoted to ordinary rotation crops, it is pretty certain that it would only be under local circumstances as to soil, climate, and markets, specially suited to the production and sale of some or all of the smaller articles which have been enumerated, that the small cultivator could hope to compete with those who now supply us with so much of them.

It follows, from the facts adduced, that there is little hope

that a system of small holdings can ever be carried out in this country to anything like the extent which experience has shown to be practicable in the countries that are so frequently held up to us as models by those unacquainted with the conditions essential to success, or even with practical agriculture at all. Indeed, no one who looks carefully into the facts of the subject, which is pre-eminently a practical one, can entertain any hope that the system of small holdings can be carried out to any such extent as to counteract at all materially the flow of the rising rural populations into the towns.

General Considerations and Conclusions.

There can be no doubt that free trade in corn and other necessaries of life has contributed immensely to the prosperity of the country at large, and of the urban populations especially; though the rural populations have also benefited much from the cheapening of their staple foods. But one of the inevitable consequences of greatly increased imports, and reduction in price, has been to reduce the area under grain crops, and therefore the area under the plough, in our own country; a necessary result of which is, to reduce the labour required to a given area, and so naturally to reduce the rural population. Nor is it very reasonable for the urban populations to complain, if an unavoidable result of the competition with foreign grain producers, and the consequent reduction in price, chiefly in their interest, has been a less requirement for rural labour, which, together with a rapidly increasing population, has led many to leave the country, and either to go into the towns or to emigrate.

It seems, however, to be assumed, in the arguments laid before the non-agricultural public, that we should produce at home not only all the smaller articles of higher value which have been referred to, but even all the grain required, if not even the meat also. Such an argument is too absurd to deserve serious refutation; but it may be well to state some of the results which such a supposition would involve.

Briefly stated, the facts are, that notwithstanding all the emigration that has so far taken place, the population of the United Kingdom has increased by more than 10,000,000, corresponding to nearly 40 per cent., during the last forty years (1851 to 1891). Under the influence of free trade in grain, so essential for the prosperity of the country in other respects, the area under wheat has, comparing the first four with the last four of the last forty harvest-years (1852–3 to 1891–2), been reduced by about 38 per cent., and the total home produce of the crop has declined

in nearly the same proportion. The imports of this staple article of food of the people have, on the other hand, increased by about 300 per cent.; with a result that, whilst during the earlier years of the period only about one-fourth of the wheat consumed was imported, in the later years more than two-thirds have been obtained from foreign sources. Lastly, a very important consideration for the home producer has been, that the price of wheat per quarter has gone down from an average of 57*s.* 8*d.* over the first eight of the last forty harvest-years to only 32*s.* 5*d.* over the last eight years, corresponding to a decline of 44 per cent. It may be added that the average price for the month just past (August, 1892) was below 30*s.* per quarter.

Further, as a natural result of increased foreign competition, and reduction in price, our own area under barley has also somewhat diminished. A result of the reduction of grain area is that, comparing the first five of the last twenty-five years (the period for which official returns are available) with the last five, our total arable area has diminished by about 2⅔ million acres, though that of permanent grass has in a much greater degree increased, and with this our live-stock has increased, and the total agricultural area has also increased. According to the returns, the area under permanent grass has increased by nearly 4⅔ million acres, and that of the total agricultural area by nearly 2 million acres; or, to put it in another way, the arable area has diminished by more than 11 per cent., the area under permanent grass has increased by more than 20 per cent., and that of the total agricultural area has increased by more than 4 per cent. But, at any rate so far as the increase in permanent grass, and that in total agricultural area, are concerned, the figures are probably too high, part of the result being doubtless due to the inclusion in later years of areas not previously returned as permanent grass.

It may be observed that a series of unproductive seasons, not only in our own country but in Western Europe generally, which culminated in 1879, but continued for some years later, led to a more rapid reduction in our own area under the crop, and concurrently to the opening up of large wheat-growing areas in various parts of the world, and at the same time to greatly increased imports. But, owing to the great reduction in price consequent on the increased production in various countries, the rate of extension of the wheat-growing areas, especially in the United States, received some check about eight or ten years ago.

It has, indeed, been estimated, judging from the increase of the population in the United States in the past, that the Central, Northern, and Western States, from which we now

derive such large supplies of grain, will, before many years have passed, be as densely populated as the Eastern States are now, and that then the export of grain will be rapidly diminished. In this calculation, however, the essential difference in the character of the land in the Eastern States and in the prairie districts of the Central, Northern, and Western States, is not taken into account. At present our imports come chiefly from large areas of formerly prairie land, often as rich as a ploughed-up old pasture in our own country, and sometimes so to the depth of some feet. The land is only skimmed, practically no labour is bestowed on cleaning, and a very small produce of grain per acre is obtained compared with that which such land properly cultivated should yield. So long as the population is sparse, the grain is harvested, the straw generally burnt, and the manure of the working stock sometimes floated away on the ice in the rivers or otherwise wasted, and grain is grown for several years in succession. As population becomes more dense, however, local markets will arise for rotation products, stock will be kept, the straw and the manure will be utilised, cultivation will be improved, and there will for some time be more rich prairie land to bring under the plough; so that it is probable that it will be long before increased density of population in those States will materially diminish the capability of production for export. The same may be said of Canada in a less degree; whilst the resources of the rest of the world, taken as a whole, show no signs of diminution.

There can, in fact, be little hope that, with the greatly increased foreign competition that has been so thoroughly established, our own wheat-growing area will ever regain its former proportions; unless, indeed, it should happen, from unforeseen causes, that the price were to range much higher than that which has prevailed in recent years. But to produce the whole of the wheat we require for consumption would involve a vastly larger extension of our own wheat-growing area than this. Thus, the area under wheat in the United Kingdom during the last eight years has averaged rather less than one-eighth of the total arable area, and to produce all the wheat required for consumption, more than one-third of our existing arable area would be required; or, if the area devoted to other rotation crops were to continue to bear about the same relation to that under wheat as in recent years, the total arable area would have to be increased nearly three-fold, making in all much more than our present total arable and permanent grass areas put together! Or, if the wheat were to be grown on a larger proportion of the existing arable area, it could obviously only be by the exclusion of the growth of other grain crops and stock foods, which would then in their turn have to be imported in larger

quantities; or our stock must be reduced, and our imports of live animals and meat very much increased.

The above considerations clearly show the absurdity of the supposition that, even with our present population, to say nothing of continued increase, and with proportionally very little possible increase in our own total food-producing area, there is any hope that our imports, at any rate of staple articles of food, can be at all materially reduced. Indeed, when it is considered how rapidly the population and the requirements for its maintenance increase, whilst the aggregate home production (though the produce per acre is greater than in any other country in the world) can increase but little, there can be no hesitation in deciding that, in spite of whatever may be done to increase the produce of the land, at any rate in smaller articles, by the establishment of small holdings or by any other means, the only alternatives are increased emigration, or increased imports of the staple foods of the people. The latter alternative, of course, involves the assumption that if the population remaining at home continues to increase as heretofore, sufficient wages could still be earned by the increased numbers for the purchase of the foreign food required.

Although to establish a large number of the population on the land in small holdings would not only be very costly, but would only to a limited extent, and under favourable conditions, be attended with success, it is nevertheless very desirable that the sale and purchase of land should be rendered as cheap and easy as possible. Further, it would doubtless be for the benefit of the country, that the owner of landed property should be absolute owner, with power to sell, or lease, or will it, to whomsoever he pleases, and that his successor should have the same power as himself. It would, in fact, be desirable to remove all restrictions to the transfer of land, and to its acquirement on equitable terms, so that there should be no artificial obstacles in the way of the small holder, who would then succeed if the conditions were suitable, but would not if they were otherwise. It would, at the same time, be desirable that those who vote the land and the money for small holdings should also be held responsible for the failures and losses. The country would thus have the security of the instinct of self-preservation in ratepayers, or whoever else was responsible, that large sums would not be expended in utopian, retrograde, and losing schemes.

J. B. Lawes.
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WHEAT

HOME PRODUCE, IMPORTS,

CONSUMPTION, AND PRICE OF WHEAT

OVER 40 HARVEST-YEARS,

1852–3 TO 1891–2.

BY

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HOME PRODUCE, IMPORTS, CONSUMPTION, AND PRICE OF WHEAT, OVER FORTY HARVEST-YEARS, 1852–53 TO 1891–92.

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INTRODUCTION.

IN 1863, and each year since, an estimate of the Home Produce of Wheat in the United Kingdom has been published by us in the daily and agricultural papers soon after harvest. An estimate of the total requirement for consumption within the then current harvest-year has at the same time been given; also an estimate, as forecast, of the requirement from stocks and imports within the harvest-year. In 1868, we gave in this Journal (Vol. VI., 2nd Series, Part 2) records and estimates on the subject for a period of sixteen harvest-years, from 1852–53 to 1867–68 inclusive. In 1880, in the *Journal of the Statistical Society* for June, and some months later in this Journal (Vol. XVI., 2nd Series, Part 2, 1880), with further particulars for the then current harvest-year added, the estimates and records were brought up to 1879–80 inclusive, completing a period in the

one case of twenty-seven, and in the other of twenty-eight years; and the basis, and the results, of the estimates so far, were passed in review. Lastly, in *The Field* of February 12, 1887, the records were brought up to 1885–6, and some points were considered in reference to current discussions at the time. It is proposed in the present paper to bring up the records to date, thus completing a period of forty harvest-years, from 1852–53 to 1891–92 inclusive.

The completion of a period of forty years would of itself be a sufficient reason for recurring to the subject, for bringing up the records to date, and for discussing the results with the view of determining how far the annually published estimates of the yield of the home-crop, of the requirements for consumption, and of the amounts to be provided by stocks and imports, have been borne out by the subsequent actual records of the net imports. Another and important reason for recurring to the subject at the present time is, however, the fact that, in 1891, the *Board of Customs*, the *Board of Trade*, and the *Board of Agriculture*, adopted a different weight per bushel in converting the recorded hundredweights of imported wheat into quarters, and, what is of more importance, they at the same time adopted a new factor for the calculation of imported "wheat-meal and flour" into its equivalent of wheat.

Further, we understand that the Registrar-General's annually published estimates of the population at the middle of each year, between one census period and another, are founded on the rate of increase actually ascertained to have taken place between the two preceding censuses, but that after the next census results are obtained, showing the actual increase, correction is made if necessary for each of the years of the previous intercensal period. It happens that the corrections so made from time to time are brought together in the Registrar-General's 53rd Annual Report, issued in 1891, and they are found to affect the numbers we have previously given for the population —that is, for the number of consumers—from 1860–61 up to the present time, sometimes in the direction of decrease, and in others of increase, more or less considerable; and it is proposed to adopt these corrections accordingly, as will be fully explained farther on.

Obviously it is desirable to adopt in the future, in our annual estimates, the new factors above referred to, for the conversion of imported flour into its equivalent of wheat, and of hundredweights of imported wheat into quarters; and also, as far as possible, to take into account any correction of the population that is available. Thus, if the population be taken at too low a

figure, the estimate of requirement for consumption will be too low, or if the estimate of population be too high, so also will that of consumption be too high. Again, if the amount of flour imported represents a larger amount of wheat grain than has hitherto been supposed, the amount available each year, and consequently the amount available per head of the population, has been greater than has been estimated. On the other hand, the reduction in the adopted weight per bushel of the home and imported wheat, although it implies an increase in the figure representing the measure of the wheat grown, imported, and consumed, does not represent any increase in the actual quantities by weight.

It is proposed to consider—the methods and the results of the estimates and records for the past forty years, as previously given; how far they require modification, in view of the altered factors in regard to imported wheat and flour, and the corrected estimates of the population, as above referred to; and whether any, or what changes, should be adopted in the future. Lastly, attention will be directed to the important bearings of the results finally arrived at.

The Data Required.

In our first paper on the subject, published in this Journal (Vol. IV., 2nd Series, Part II.) in 1868, the estimates and records were given for each division of the United Kingdom separately, and for the whole collectively, but in 1880 the illustrations were confined to the United Kingdom as a whole, and it is proposed so to limit them on the present occasion.

For each harvest-year the data required are—the area under wheat; the average yield of wheat per acre over the whole country; the aggregate home produce, and the amount of it available for consumption; the net imports; the population; and the average consumption of wheat per head of the population per annum.

The data at command in 1868, and the results arrived at, were fully discussed in the paper of that date, and for detailed information reference must be made to it, but the main facts may be briefly summarised as follows:—

The Area under Wheat.—For the fourteen years 1852 to 1865 inclusive, estimates only were available for fixing the area under the crop in England and Wales. For Scotland, returns were collected by the Highland Society for the years 1854, 1855, 1856, and 1857; but for the two years prior to 1854, and for the eight years 1858–65 inclusive, estimates only had to be relied upon. For Ireland, returns have been available from the

commencement of our inquiry up to the present time. For 1866, and for each year since, thanks to the exertions of the late Sir James (then Mr.) Caird, we have an official record of the area under the crop, in each division of the United Kingdom, and in the whole collectively, in the "Agricultural Returns" annually published about the time of harvest. For the last twenty-six years, therefore, one element of uncertainty in any estimates of the home produce of wheat has been removed.

The Average Yield of Wheat per Acre.—For 1884, and each year since, estimates of the average yield of wheat per acre in England, Wales, Scotland, Great Britain, Ireland, and the United Kingdom as a whole, have been published by the Board of Agriculture, in the "Agricultural Produce Statistics." But, prior to that date, the only returns or official estimates at command relating to the subject were, for Scotland for four years, 1854–57, and for Ireland for each year within the period of our inquiry; whilst, for England and Wales, comprising in the earlier years from 85 to 90, and in the later nearer 95, per cent. of the total area under the crop, there was no official information whatever for any year prior to 1884, as above referred to. For this large proportion of the United Kingdom it was, therefore, after very full consideration of the data, and of the results to which they led, decided to adopt the average produce per acre each year on certain selected and very differently manured plots, in the permanent experimental wheat field at Rothamsted, as the basis of the estimates of the average produce per acre each year; and the same data have been relied upon in forming an estimate of the average produce over the United Kingdom as a whole. But, having regard to the character of the soil of the experimental field at Rothamsted, to the characters of the individual seasons, and to the consideration whether the season was more favourable for heavy or for light land, and so on, the estimate actually adopted for the country at large has, in some seasons, and especially in bad seasons, differed somewhat from the actual average indicated on the selected plots in the experimental field. Lastly, in all cases, the actual number of bushels per acre has been reduced by calculation into bushels of the adopted weight of 61 lb. per bushel.

For detailed discussion, and for illustrations of the applicability of the data for the purposes of an estimate of the yield of the country at large, so far as evidence was available at that time after adopting them for a period of sixteen years, we must refer to our first paper on the subject published in the Journal in 1868; and for further discussion, after the application of the data for a period of twenty-eight years, to our papers given in the *Journal*

of the Statistical Society, and in this Journal, in 1880, as already referred to. We have now, however, experience in the use of such data for a period of forty years; and, with this aid, it is proposed further to examine into their validity, and to the trustworthiness of the results arrived at, as tested by subsequent knowledge, and by the accordance or otherwise of the results so obtained, with conclusions arrived at with regard to other elements of the question.

The Aggregate Home Produce, and the Amount of it available for Consumption.—It is obvious that if the area under the crop, and the average yield per acre, are known, the aggregate home produce is very easily calculated. In estimating the amount of the total produce which is available for consumption, deduction has to be made for the amount annually returned to the land as seed. As explained in our first paper (in 1868), we then assumed 2¼ bushels per acre (calculated on the acreage of the past year for the next) to be on the average so returned to the land; and this amount was deducted from the aggregate produce for each year from 1852 to 1886 inclusive; but, for 1887 and each year since, only 2 bushels per acre have been deducted from the total home produce in estimating the amount available for consumption.

The imports.—For the whole of the period to which our inquiry relates, returns have been available for the United Kingdom collectively, either of the net imports of wheat and of wheat-flour, or of the imports and exports from which the net imports could be calculated. For the separate divisions of the country the returns have not been so complete; and, mainly for this reason, we have, since our first paper, in 1868, confined attention to the United Kingdom as a whole. For the United Kingdom, returns are available for the individual weeks or months; and, as our estimates are made, not for calendar, but for "harvest-years," that is, from September 1 of one year to August 31 of the next, the records enable us to calculate the net imports for the exact period required.

The Population.—The Registrar-General publishes an estimate of the population at the middle of the calendar year for every year between one census and another; and from these data we have calculated the average number of consumers for the harvest-year. The middle of the calendar year being the end of June, and the middle of the harvest-year the end of February, the plan adopted has been to add to the number recorded for the preceding midsummer two-thirds of the difference between that figure and the number given for the next midsummer, thus bringing the estimate up to the end of

February. Of course, this can only be done after the record for the second midsummer is published, and hence the same plan is not available in estimating the population of the then current harvest-year soon after harvest each year. For this purpose, the plan has been to estimate the increase of population since the preceding midsummer up to the end of the following February (the middle of the harvest-year) at the same rate as that indicated by the recorded increase during the three months prior to the preceding midsummer. Such estimates can obviously be only approximate, and it has been suggested to us that it would be more correct to adopt the rate of increase on the whole preceding twelve months instead of on the three months only. This we did in our estimate for the then current harvest-year soon after harvest last year, and we propose to do the same in future. But, under any circumstances, the annually published estimates are only provisional; and, as above intimated, in any publication of the estimates of the average population, for the individual harvest-years, subsequent to the publication of the record for the second midsummer, the figure obtained during the current harvest-year has always been corrected accordingly. The results show some irregularities of increase, especially immediately after the census years, presumably from a new factor being then adopted for the calculation of the annual increase of population during the intercensal period. It will be seen further on, however, that some, and sometimes even material, corrections, beyond those above referred to, should be made, for some of which the data have not been available until quite recently.

The Average Consumption of Wheat per Head of the Population per Annum.—Previously to the publication of our first paper on this subject in 1868, a higher figure had generally been assumed than we were then led to adopt. For England and Wales we founded an estimate of the average consumption per head of the population, on the calculation of eighty-six different dietaries, arranged in fifteen divisions, according to sex, age, activity of mode of life, and other circumstances; and the result so obtained was compared with that arrived at on the basis of population, and of the amounts of the estimated available home produce, and of the net imports, of wheat each year. For Scotland and for Ireland it was only possible to found an estimate on the basis of population and the estimated amounts of the home and foreign supplies. On these bases, the average consumption of wheat in the United Kingdom collectively was reckoned at 5·1 bushels (of 61 lb. per bushel) per head of the population per annum during the first eight years, 1852–53 to 1859–60, and at

5·5 bushels during the second eight years, 1860–61 to 1867–68; and in the subsequent annually published estimates that figure was adopted up to 1879–80 inclusive. But, on the review of the estimates and their results in our second paper, in 1880, the consumption was estimated at 5·6 bushels during the third eight years, and 5·65 subsequently; and this last figure has been adopted since that date, that is, from 1876–77 up to the present time. The correctness of this estimate in the past, and its continued applicability in the future, will be considered farther on.

Reconsideration of the Data.

From the foregoing review it results that, so far as the area under the crop, and the amount of the imports, are concerned, the same data must be relied upon as heretofore. But, in regard to the average produce of wheat per acre over the United Kingdom each year, the estimates of the population each year, and those of the consumption per head of the population, the basis of the estimates, and the results arrived at, will now, after the experience of forty years, and with the further information available, be submitted to careful re-examination, and be confirmed or corrected accordingly, as the case may be.

The Estimates of the Average Produce of Wheat per Acre in the United Kingdom each Year.

We will first consider the validity of the estimates of the average yield of wheat per acre over the United Kingdom each year. As already stated, they have been founded on the average produce obtained on certain selected plots in the field at Rothamsted, which is now growing the crop for the fiftieth year in succession—without manure, with farmyard manure, and with various artificial manures. There has been no change in the treatment of either the unmanured or the farmyard manure plot since the commencement of the experiments in 1843–44. There were, however, some changes in the manures applied to the various artificially manured plots during the first eight years, that is, to 1850–51 inclusive. But, for all the subsequent crops, from 1852 up to the present time, two of the three selected artificially-manured plots have, respectively, received exactly the same manure each year, and the third has done so for a period of thirty years from 1854–55 to 1883–84; after which, from 1884–85 and since, another plot has received the same manures, and from that time the results obtained on it have been brought into the calculation, as further explained below.

The selected plots are :—

Plot 3. Unmanured every year, commencing 1843–44.

Plot 2. Fourteen tons farmyard manure every year, commencing 1843–44.

Plot 7. Mixed mineral manure, and 400 lb. ammonium-salts, each year, commencing 1851–52.

Plot 8. Mixed mineral manure, and 600 lb. ammonium-salts, each year, commencing 1851–52.

Plot 9 (or 16). Mixed mineral manure, and 550 lb. sodium nitrate, each year, thirty years, 1854–55 to 1883–84, on Plot 9; and the same manures on Plot 16, 1884–85, and each year since.

In forming the estimate of the average produce per acre in the United Kingdom each year, the plan has been to take the mean produce of the unmanured plot, the farmyard-manure plot, and of the three artificially manured plots reckoned as one, and to reduce the result so obtained to bushels of the adopted weight of 61 lb. per bushel. As will be shown farther on, experience has proved that this mode of computation leaves little to be desired as a means of estimating the average yield of the country at large over a number of years, and indeed for most individual years. It has not, however, been found equally applicable for every individual year. Careful comparison leads to the conclusion, that the so calculated average produce per acre, on the selected plots, probably gives somewhat too high a result for the country at large in seasons of great abundance, and too low a result in very unfavourable seasons. Accordingly, as already referred to, in some seasons, instead of the actual average indicated by the experimental plots, a higher or a lower figure has been adopted; and, especially in the case of some bad seasons, a higher one has been taken.

Independently of any such admitted occasional differences between the so directly calculated, and the actually adopted, estimates for individual years, the questions arise—whether the average result indicated by the several selected plots remains as applicable as heretofore? Or whether the produce of some of them is annually declining, or that of others annually increasing, irrespectively of the influence of season; so as to vitiate the continued applicability of the results for the purposes of the estimate for which they have hitherto been employed? This point was carefully considered in our paper in 1880, on a review of the results obtained up to that time, that is, over a period of twenty-eight years; and, with the additional experience now extending to forty years, we on the present occasion submit it to further detailed re-consideration.

The Unmanured Plot.—There can be no doubt that the produce of this plot has gradually declined; and, independently of the evidence of diminishing produce, analyses of the soil, at different periods, show that there has been a gradual diminution in the amount of nitrogen in it. But, owing to the great fluctuations in the amount of produce from year to year dependent on season, it is by no means easy to estimate the decline due to exhaustion of the soil, as distinguished from variations due to the seasons.

In the first place it is difficult to say what figure should be adopted as the standard produce of the plot by which to compare the yield from year to year. The whole field was manured with farmyard dung in 1839, and then grew turnips (fed on the land), barley, peas, wheat, and oats, before the commencemeut of the experiments in 1843–4. The plot then grew eight crops of wheat without manure, to 1850–1, before the commencement of the period to which our present estimates refer. Although, at the conclusion of the five-course rotation since manuring above described, the land would doubtless be, in an agricultural sense, so far exhausted as to require re-manuring, there can be no doubt that there would nevertheless be some accumulation due to comparatively recent manuring and cropping. It would be supposed, however, that the growth of wheat for eight years in succession without manure would remove most, if not all, accumulation which could be attributed to comparatively recent treatment. Indeed, there can be little doubt that the land would suffer more or less exhaustion during those eight years; but, as serving to counteract the tendency to decline in yield from exhaustion during that period, it happened that, taken together, those eight seasons were of more than average productiveness.

Upon the whole, therefore, it was, in 1880, considered that the average produce of those eight years, which was 17 bushels per acre, at 61 lb. per bushel, might be taken fairly to represent the standard produce of the unmanured land, independently of material exhaustion. Adopting this as the standard, we endeavoured to estimate whether, or to what extent, there had been decline in yield during the twenty-eight years, due to exhaustion, independently of variations due to season. To this end we first endeavoured to calculate what should be the produce in each year subsequent to the first eight, provided there were no decline from exhaustion, but only variation from season. Assuming that, if there were no exhaustion, it would each year fluctuate from the standard under the influence of season in the same proportion as the fluctuation of the adopted average yield

of the country at large, the produce that the unmanured plot should yield each year has been calculated; and the difference between the result so obtained and the actual yield of the plot each year shows the excess or deficiency of the actual produce, and, if deficiency, indicates the decline due to exhaustion.

In 1880, with the results for twenty-eight years then at command, such a calculation showed an average deficiency over the period of rather more than 4⅜ bushels. This, therefore, according to the mode of calculation adopted, represented the decline of the produce on the unmanured plot during that period irrespectively of season. The results further showed that, supposing the decline had been uniform over the whole period, it would correspond to a rate of diminution of between one-quarter and one-third of a bushel from year to year. It was suggested, however, whether with a return of better seasons the decline would be as marked. In reference to this point it may be stated, that the last nine of the twenty-eight years gave a lower average produce over the country at large than any equal period of the previous nineteen or of the succeeding twelve years; and that they gave an average of only 9 bushels per acre on the unmanured plot against 12⅜ bushels over the succeeding twelve years. Following the same line of calculation for forty years, with, as above referred to, a return of better seasons, especially during the last eight or nine years, to 1891 inclusive, the figures showed almost exactly the same average deficiency of actual produce, compared with the standard of 17 bushels, over the forty years as was formerly found for the twenty-eight years, namely, 4½ bushels, against rather more than 4⅜ bushels over the twenty-eight years. This, if the decline had been uniform, would correspond to less than a quarter (about two-ninths) of a bushel per acre from year to year over the forty years, instead of nearly one-third of a bushel over the twenty-eight years. But even this reduced rate of decline, due to a return of better seasons, indicated a calculated produce on the unmanured plot of only about 8 bushels in the fortieth year, against an actual produce over the last three years of about 13 bushels; and it showed an average of only about 9 bushels over the last ten years, against an actual average of nearly 12½ bushels.

It was concluded, therefore, that the adopted standard of 17 bushels showed a greater decline than was indicated by the actual produce obtained, and that that standard was too high. Accordingly, the calculations have now been made on the assumption that the standard unmanured produce with which to compare the actual produce, as influenced by exhaustion, was only 16 bushels.

Adopting 16 bushels as the standard, the result is, that with an average actual produce over the twenty-eight years of rather over 12½ bushels, the average decline is less than 3½ instead of nearly 4½ bushels when 17 was taken as the standard; and the rate of decline from year to year is rather less than one-quarter of a bushel, instead of, as before, nearly one-third of a bushel. And, whilst with a standard of 17 bushels the calculated produce in the twenty-eighth year was little more than 8 bushels, with a standard of 16 bushels it is more than 9 bushels.

Then, the results for forty years show, with a standard of 16 bushels, and an actual average produce of about 12½ bushels, an average decline of about 3½, instead of about 4½ bushels with a standard of 17 bushels; and the average rate of reduction from year to year is little more than one-sixth of a bushel instead of nearly one-quarter of a bushel, with 17 bushels as the standard. Further, whilst with 17 bushels as the standard, the calculated produce would amount to little more than 8 bushels in the fortieth year, showing a deficiency of nearly 9 bushels, with a standard of 16 bushels the calculated produce would be more than 9 bushels in the last year, and the reduction less than 7 bushels since the beginning.

Upon the whole, therefore, assuming the standard produce of the unmanured plot to have been 16 bushels per acre independently of material exhaustion, there was an average decline from year to year of rather less than a quarter of a bushel over the twenty-eight years, and of little more than one-sixth of a bushel over the forty years. It will be seen that a return of better seasons since the first twenty-eight has led to a considerable reduction in the estimate of the rate of decline from year to year due to exhaustion. It remains to be seen what will be the result in the future; and whether a point has already been, or will in time be reached, at which the produce will remain constant, excepting so far as it is influenced by the fluctuations of the seasons.

The Farmyard Manure Plot.—It has been seen that the unmanured plot has declined in yield and fertility; but there can be no doubt that the farmyard manure plot has, on the other hand, increased in fertility. Analyses of the surface soil at different periods has shown that it has become about twice as rich in nitrogen as that of the unmanured plot. It has, indeed, been shown on several occasions, that a large amount of the constituents of farmyard manure accumulates within the soil, and that they are very slowly taken up by crops; in fact, notwithstanding this great accumulation within the soil, the wheat crops on the dunged plot seldom, if ever, show over

luxuriance; and in unfavourable seasons the produce has been comparatively small, largely owing to the encouragement of weeds, and especially of grass, which, in wet seasons, it has been impossible effectually to eradicate, and what has been done has not been accomplished without injury to the crop.

In writing upon the results of the twenty-eight years, 1852–1879, we adopted, as in the case of the unmanured plot, the average of the preceding eight years, 1844–51, to represent the standard yield of the farmyard manure plot, irrespectively of material accumulation. The figure so arrived at was 28⅛ bushels at 61 lb. per bushel. Adopting this as the standard produce of the plot, then calculating what would be the produce in each of the subsequent twenty-eight years, provided it fluctuated from the standard from year to year in the same degree as the fluctuation of the average produce of the country at large, and then taking the difference between this calculated produce fluctuating by season alone, and that actually obtained each year, the result indicated the increase, if any, due to accumulation. On this mode of calculation, the average increase due to accumulation would amount, over the twenty-eight years, to about 5 bushels; and the average rate of increase from year to year, provided it were uniform throughout the period, would be rather less than ⅛ of a bushel.

Adopting the same amount, 28⅛ bushels, as the standard yield, and following the same line of calculation for the forty years, the average increase would amount to rather over 6¼ bushels, and the rate of increase from year to year, if uniform throughout the period, would be rather less than one-third of a bushel; that is, less per annum over the forty than over the twenty-eight years, which, towards the end, included a series of very unfavourable seasons.

Such are the results for the twenty-eight and for the forty years, on the assumption that the standard produce of the farmyard manure plot, irrespectively of material accumulation, was only 28⅛ bushels. This is, however, certainly a very low produce to be obtained by the annual application of 14 tons of farmyard manure per acre for eight years in succession, and in seasons which, taken together, were of more than average productiveness. If, however, we exclude the produce of the first of the eight years, 1844, which gave a high yielding crop over the country at large, but less than 20 bushels on the farmyard manure plot, the average of the remaining seven years amounts to 29·3 bushels, whilst three of the seven yielded more than 30 bushels, and two others 29 bushels or more. Adopting 29·3 bushels as the standard instead of 28⅛, the result would be an

average increase of only about $3\frac{3}{4}$ instead of about 5 bushels over the twenty-eight years, and of only $5\frac{1}{8}$ bushels instead of $6\frac{1}{4}$ over the forty years; whilst the average increase from year to year, if uniform throughout the period, would be little more than one-quarter of a bushel instead of nearly $\frac{3}{8}$ of a bushel over the twenty-eight years, and little over one-quarter of a bushel instead of nearly one-third of a bushel over the forty years.

The general result is, then, that if we exclude the produce of the first of the eight preceding years (1844), which the fact of the high produce over the country at large, and the low produce of the experimental plot, seems fully to justify, we get a standard produce of the farmyard manure plot of 29·3 instead of $28\frac{1}{8}$ bushels by which to calculate the subsequent increase from accumulation; and the estimated rate of increase is accordingly lower.

The Artificially-manured Plots.—Neither the previous history of the plots, nor common experience, enables us to adopt a standard average produce for the respective manures, with which to compare the actual produce each year, so as to form a judgment whether there has been progressive decline or progressive increase in the productive effect of the manures irrespectively of fluctuations dependent on season. If we take the average produce of either of the plots over the twenty-eight or the forty years as its standard produce, and then take the difference between this standard and the actual yield each year, we get more or less difference, sometimes plus and sometimes minus in the individual years, according to the characters of the season; but over the total period of twenty-eight or forty years, the average of which is taken for the standard, the pluses and the minuses necessarily balance one another; showing, therefore, neither progressive decline nor progressive increase due to the manure.

A careful study of the results in detail also indicates that there is practically no appreciable variation from year to year in the produce of the respective manures, other than that obviously attributable to the seasons. Or, if we divide the total period into a number of shorter ones, the difference of result for each of the shorter periods is again seen to depend on the favourable or unfavourable conditions of the seasons included. On the other hand, the examination clearly shows, that the selected artificially manured plots give a proportionally higher produce in seasons of high productiveness than the excess over the average in the country at large would indicate. In other words, so far as the yields of the selected artificially manured plots are brought into the estimates, they tend to indicate somewhat too high a

produce in the better seasons, and somewhat too low a produce in unfavourable seasons.

If, then, as a careful examination of the facts seems to indicate, the yield of the unmanured plot has somewhat declined from exhaustion, and that of the farmyard manure plot has in a rather greater degree increased from accumulation, whilst the produce of the selected artificially manured plots has not changed otherwise than from year to year, according to the fluctuations of the seasons, the question arises whether, or to what extent, the average results of the whole of the selected plots should be considered inapplicable as a basis for estimating the yield for the United Kingdom each year, either during the past forty years, or in the future.

In order to form a judgment on this point, the produce of the unmanured plot in each of the past forty years has been increased in the proportion in which the previous calculations showed that there had probably been decline from exhaustion, and that of the farmyard manure plot has been reduced in the proportion in which the calculations showed that there had probably been increase from accumulation. That is to say, the actual results have been corrected on the assumption that there had been neither decline from exhaustion in the one case, nor increase from accumulation in the other. Then, the average of the thus corrected produce of the unmanured and of the farmyard manure plot, and of the three artificially manured plots (which are supposed not to have changed) taken as one, has been calculated, and this corrected or calculated average produce of the selected plots each year has then been deducted from the average of the actual average results, the difference showing the excess of the actual over the calculated result each year, due to the greater increase by accumulation on the farmyard manure plot, than decline by exhaustion on the unmanured. The result indicates an average over the forty years of rather more than half a bushel excess of produce per acre per annum; and an excess of rather over a bushel in the fortieth year, supposing the rate of increase had been uniform throughout the period. Whether or not this change vitiates the applicability of the data as hitherto used, or their utility for the same purpose in the future, will be better seen farther on.

It has already been explained, that the average produce of the selected plots probably indicates somewhat too high a result for the United Kingdom in seasons of great abundance, and too low a result in very unfavourable seasons, and that, accordingly, in some seasons a higher or a lower figure has been adopted; but that the estimates so founded on the produce of

the selected plots have, as a matter of fact, been proved to be very near the truth for series of years, and in most cases for individual years also. Illustrations of this will be adduced farther on.

The Results for the Forty Years, according to the previously adopted Standards.

Appendix-Table I. (p. 58) gives the particulars of the home produce, the imports, and the consumption, of wheat in the United Kingdom, for the forty harvest-years, 1852–3 to 1891–2, in the same form as published in former papers for shorter periods. The area under the crop, the estimated average produce per acre, the total home produce each year calculated therefrom, and the amount available for consumption after deducting the quantity required for seed, are, for the first twenty-eight years, the same as given in our last paper on the subject in this Journal (Vol. XVI., 2nd Series, Part 2, 1880); and for the subsequent years they are, with some immaterial subsequent corrections, the same as given in the annual letter on the wheat crop of the country.

The net imports (imports less exports) have, however, been recalculated throughout on one uniform basis. Thus, the same source is now adopted throughout, namely, the *Trade and Navigation Returns*, which formerly had not been used for the earlier years; and we have now to thank Mr. Giffen, of the Board of Trade, for kindly giving us access to the records. Again, for the earlier years, the quantities of wheat returned in cwts. were calculated into equivalent quarters, and the quantities of "wheat-meal and flour" returned in cwts. into their equivalent quarters of wheat, by factors not always precisely corresponding with what seem to have been the officially adopted relations. Now, the wheat imported as wheat, and returned in cwts., has been converted into quarters, as we understand had been done by the Departments, by multiplying the cwts. by $\frac{3}{13}$, which gives quarters of 485$\frac{1}{3}$ lb.=8 bushels of 60$\frac{2}{3}$ lb. per bushel; and the imported "wheat-meal and flour," returned in cwts., has been calculated into quarters of wheat (also as we understand had as a rule been done by the Departments) by reckoning 3$\frac{1}{2}$ cwts. of "wheat-meal and flour" to be equivalent to a quarter of wheat. This calculation corresponds to 80·77 by weight of "wheat-meal and flour" to 100 of wheat; and it gives the result in quarters of wheat of 60$\frac{2}{3}$ lb. per bushel. In some of the earlier years, however, it is stated in the Returns that 1 cwt. of "wheat-meal and flour" was taken as equivalent to 1$\frac{1}{4}$ cwt. of

wheat, which corresponds to 80 parts by weight of "wheat-meal and flour" to 100 of wheat.

The general result of the adoption of the above data, and of the slightly altered modes of calculation, has been to make changes which are practically immaterial; but it was thought better, on republication, to have the results calculated uniformly throughout.

The population is taken as before; but, as will be seen farther on, the figures will be subject to some alteration for the intercensal years, according to corrections subsequently published by the Registrar-General.

It is obvious that the alterations in the calculation of the imports, as above described, will slightly, though quite immaterially, affect the calculations of the amount of wheat available for consumption per head from home and from foreign sources respectively, within each year, and also the sum of the two.

Appendix-Table I. (p. 58) therefore gives, with what have turned out to be immaterial corrections, a complete record of the home produce, imports, and consumption, of wheat over the forty years of our estimates, so far as already published, either in our former papers or in the annual estimates; and before applying to the estimates of the past, the alterations or corrections which we have stated will be necessary in the future—in accordance with the altered standards recently adopted by the Departments in the calculation of cwts. of wheat into quarters, and of cwts. of "wheat-meal and flour" into quarters of wheat, and with the corrections of the population since recorded by the Registrar-General—it will be instructive to consider the bearing of the results obtained without these alterations, for the period of forty years, as formerly for shorter ones.

We will first compare in this way the directly calculated average produce of the selected experimental plots at Rothamsted, with the annually adopted estimate of the average produce of the United Kingdom founded upon them; and next show how far the adopted estimates have been borne out by other evidence bearing upon the subject.

The following Table (I.) shows, for each of the first four eight-yearly periods, for the next five years, and for the total thirty-seven years, 1852–88 inclusive,—also separately for the last three years, 1889–91, and for the total period of forty harvest-years, 1852–91,—the produce of wheat per acre, in bushels of 61 lb., as hitherto always reckoned, as under:—

1. The directly calculated mean produce per acre on the selected plots in the experimental wheat field at Rothamsted.

2. The annually adopted estimates of the produce per acre in the United Kingdom, as founded on the results obtained on the selected plots.

3. The produce per acre, as calculated by deducting the net imports, subsequently recorded, from the total estimated requirement for consumption given as forecast each year, adding to the result the amount assumed to be returned to the land as seed, and dividing the product by the area under the crop.

TABLE I.

	Produce per acre, at 61 lb. per bushel		
	Directly calculated mean produce of the selected plots	According to annually adopted estimates	According to consumption and imports
	Bushels*	Bushels	Bushels
Averages for:—			
8 years 1852–3 to 1859–60 . .	27⅛	28	28⅛
8 „ 1860–1 „ 1867–8 . .	29	28⅜	28⅛
8 „ 1868–9 „ 1875–6 . .	27	26½	26⅜
8 „ 1876–7 „ 1883–4 . .	23	24⅞	24⅜
5 „ 1884–5 „ 1888–9 . .	29	28⅞	30¾
37 „ 1852–3 „ 1888–9 . .	27	27¼	27⅛
3 „ 1889–90 „ 1891–2 . .	30¼	30¼	26⅓
40 „ 1852–3 „ 1891–2 . .	27¼	27⅛	27⅛
5 years 1884–5 to 1888–9 . .	29	28⅞	30¾
3 „ 1889–90 „ 1891–2 . .	30¼	30¼	26⅓
8 „ 1884–5 „ 1891–2 . .	29⅛	29⅛	29⅛

It will be seen that although the Table relates to a period of forty years, the results are given for four periods of eight years and for one of five, making together only thirty-seven years; and that those for the last three years, and the average for the total forty years, are given separately. The reason is, that, notwithstanding very much labour annually bestowed on hand-hoeing, the land had, in the later years, partly owing to the characters of the seasons, become very foul; *Alopecurus agrestis* (slender fox-tail) being the most prominent and troublesome weed. Hence, for the crops of 1889, down one-half the length of the plots (the top), only alternate rows were sown, in order, as far as possible, to eradicate this and some other plants; the other half (the bottom) being sown in the usual way. For the crop of 1890, on the other hand, the full number of rows were sown on the top half, and only alternate rows on the bottom, in order

the better to clean that portion. For the crop of 1891, however, the full number of rows were again sown over the whole length of each plot.

In 1889, the produce of the ordinarily or thick-sown portion of the land was taken as the produce of the plot; and this being the bottom portion, which is the worst half of the plots, was undoubtedly abnormally low; the selected plots yielding a mean produce of only 27½ bushels at 61 lb. per bushel, whilst our actually adopted estimate was 29½ bushels.

In 1890, the top half of the plots was ordinarily sown, and this portion being not only the better half, but having been only thin-sown—that is, partially fallowed—in 1889, the produce was without doubt abnormally high; the average produce of the selected plots being 37¼ bushels, whilst we estimated the yield of the country at large to be only 31½ bushels. Accordingly, we have adopted the mean produce of the thick- and the thin-sown portions, as more nearly representing the normal produce of the plots; and this gives an average for the selected plots of 30⅞ bushels, which is not much less than our adopted average yield for the United Kingdom.

Lastly, in 1891, the entire plots were ordinarily sown, but after partial fallow of the top half in 1889, and of the bottom half in 1890. The produce was, therefore, assumed to be abnormally high. The average of the selected plots gave 32⅜ bushels at 61 lb. per bushel; but we estimated the crop of the country at only 29½ bushels at 61 lb., or 30 bushels at 60 lb. per bushel.

It was, therefore, under abnormal conditions of the land, that abnormal results were obtained in the last three years of the forty, and hence the same accordance as usual between the actual produce of the selected plots and the estimated yield of the country in the individual years was not to be expected. It is seen, however, that the average yield of the selected plots over these three years taken together was, nevertheless, identical with the estimated yield of the United Kingdom over the same three years—namely, 30¼ bushels.

Let us now consider the estimates of yield per acre calculated in the three different ways, over the individual periods, and over the total period of the first thirty-seven of the forty years. Although in the majority of seasons the mean produce of the selected plots closely represents the average produce per acre of the United Kingdom, as has already been stated it generally indicates a somewhat higher yield than the average ot the country at large in seasons of high productiveness, and a somewhat lower one in unfavourable seasons; and hence, in some

seasons, we have adopted an estimate rather higher or rather lower, as the case may be, than the exact experimental results would indicate. Accordingly, the figures show that, over the eight years 1860–1 to 1867–8, which included several of very high productiveness, the average yield on the selected plots was 29 bushels, whilst the average of the annually adopted estimates for the United Kingdom over the same period was 28⅜ bushels, or rather less. Again, over the eight years 1876–7 to 1883–4, which included some exceptionally bad seasons, the selected plots gave an average of only 23 bushels, whilst the average of the annually adopted estimates of the yield of the United Kingdom was 24⅛ bushels. Taken over the whole period of the thirty-seven years of normal treatment of the land, however, the selected plots indicate an average of 27 bushels, against 27¼, according to the annually adopted estimates. In other words, there is, over the thirty-seven years, only a difference of a quarter of a bushel per acre per annum between the direct indication of the produce of the selected experimental plots and the results of the annually adopted estimates. Lastly, even including the abnormal results of the last three years, the average for the forty years is seen to be 27¼ bushels according to the actual results of the selected plots, and 27⅛ bushels according to the annually adopted estimates, showing, therefore, a difference of only ¼ bushel over the forty years.

We will now compare the annually adopted estimates of the produce of the country at large with the results given in the last column of the Table, which are obtained by deducting the subsequently recorded net imports from the estimated total requirement for consumption, each year adding the amounts required for seed, and dividing the product by the number of acres under the crop. It is seen that, over each of the first four eight-yearly periods, there is a difference of only ⅛ bushel per acre between the average of the annually adopted estimates and the average of the results founded as above on consumption and imports over the same periods.

Over the subsequent five years, however, whilst the average of the annually adopted estimates indicates 28⅞ bushels per acre for the home crop, the calculated result founded on consumption and imports shows 30¾ bushels, or a difference of 1⅞ bushels in excess of the average of the estimates. On the other hand, over the last three years, whilst the average of the annually adopted estimates is 30¼ bushels, the result founded on consumption and imports indicates only 26⅛ bushels, or a deficiency of 4⅛ bushels. The facts are, as will be seen farther on, that the amounts available for consumption per head of the population from home

and foreign supplies taken together, were comparatively low within the five years, the imports not increasing at so rapid a rate as previously; whilst during the last three years, and especially in the last harvest-year (1891–2), the imports were very much in excess of the requirements. Hence, during the five years, the amount of imports to deduct from the requirements for consumption were comparatively low, leaving, according to the mode of calculation, a larger proportion to be apparently derived from the home produce; whilst, over the last three years, the imports being undoubtedly in excess of the requirements, deducting them from the requirements leaves a too low amount to be credited to the home crop. If, however, we take the average for the two periods of five and three years together, that is, for the last eight years, as shown in the bottom line of the Table, the average of the annually adopted estimates, and the result founded on consumption and imports, differ by only ¼ of a bushel.

Finally, taking the result for the total period of forty years in each case, the average of the annually adopted estimates, and that calculated from consumption and imports, are identical, namely 27½ bushels; whilst the actual average produce of the selected plots is 27¼ bushels.

So much for the validity, in the past, of the results of the selected plots in the experimental field at Rothamsted, as a basis for the annual estimation of the yield per acre of the United Kingdom.

We will now consider how far the estimates of the total home crop available for consumption arrived at as above, together with the actually returned net imports each year, indicate amounts consumed per head of the population from home and foreign sources respectively, and from the two together, which confirm the estimates that have been annually made of the total requirement per head of the population.

Table II. (p. 23) shows, for each of the first four eight-yearly periods, for the next five years, and for the total thirty-seven years, also for the last three years, and for the total period of forty years, the amounts of wheat available for consumption per head per annum, from home and from foreign sources respectively, and from both together, according to the estimates of the home, the actual records of the foreign supplies, and the returns of the population, as given in the Appendix-Table I. (p. 58); and, in the last column of the Table there are given for comparison, the averages for each period of the annually adopted estimates of the total requirement per head of the population. It should be added that, in these calculations relating to our past estimates, the

population for each year has been taken as adopted in our previous papers and annual estimates, which are, as has been explained, subject to alteration in accordance with corrections made from time to time by the Registrar-General, and which will be carried out in subsequent Tables.

The first point to notice in the Table is the marked reduction from period to period in the amount and proportion of the total requirement for consumption which is supplied by the home-crop. Thus, according to the figures, 3·74 bushels were obtained per head per annum from the home produce over the first eight years, and only 1·83 bushel, or less than half as much,

TABLE II.

	Available for consumption per head			Adopted total requirements per head per annum
	From home produce	From imports	Total	
	Bushels	Bushels	Bushels	Bushels
Averages for :—				
8 years 1852–3 to 1859–60 . .	3·74	1·33	5·07	5·10
8 „ 1860–1 to 1867–8 . .	3·31	2·18	5·49	5·50
8 „ 1868–9 to 1875–6 . .	2·93	2·66	5·59	5·60
8 „ 1876–7 to 1883–4 . .	2·03	3·63	5·66	5·65
5 „ 1884–5 to 1888–9 . .	1·83	3·69	5·52	5·65
37 „ 1852–3 to 1888–9 . .	2·85	2·61	5·46	5·49
3 „ 1889–90 to 1891–2 . .	1·83	4·07	5·90	5·65
40 „ 1852–3 to 1891–2 . .	2·7	2·73	5·50	5·50
5 years 1884–5 to 1888–9 . .	1·83	3·69	5·52	5·65
3 „ 1889–90 to 1891–2 . .	1·83	4·07	5·90	5·65
8 „ 1884–5 to 1891–2 . .	1·83	3·83	5·66	5·65

over the last eight years of the forty. On the other hand, imports supplied an average of only 1·33 bushel per head per annum over the first eight years of the forty, and 3·83 bushels, or not much less than three times as much, over the last eight.

Let us now turn to the third column, showing the total amounts available per head per annum from home and foreign sources taken together, and compare the results there given with those for the same periods in the last column, according to which the estimates of the requirement for consumption have been calculated each year as forecast. It is seen that, over each of the five eight-yearly periods, the amounts calculated from the estimated home-crop and the subsequently recorded imports,

agree almost absolutely with the annually adopted estimates for the same periods. For reasons already explained, however, when considering the results in Table I., the amounts calculated as available per head, from home and foreign sources together, are pretty certainly too low for the first five years of the last eight, and too high for the last three years. But, as will be seen in the bottom lines of the Table, the amount calculated as available per head per annum over the last eight years, that is, taking the five years and the three years together, is almost identical with, but very slightly in excess of, the annually adopted estimate for the period; the average amount calculated as available being 5·66 bushels, and the estimate for the period annually adopted as forecast being 5·65 bushels. Lastly, the average consumption per head per annum over the forty years is 5·50 bushels, reckoned from the amounts available from home produce and imports together, and it is absolutely the same taking the average of the annually adopted estimates of requirement per head over the same period.

Such, then, is the accordance of the estimate of the consumption per head per annum of the population, founded on the amounts of wheat available from home and foreign sources, with the annually adopted estimates of the requirement per head. It is to be remembered that these estimates of the past are on the assumption of 60¾ lb. per bushel for the doubtless somewhat drier foreign wheat, and of 61 lb. per bushel for the produce of the home crop.

Effects of the Application to our previous Records and Estimates of the recently adopted Standards or Corrections.

We have now to consider the differences which the changes in the weight per bushel of wheat, and in the relation of flour to wheat, which have been recently adopted, and also the corrections in the number of the population which have been referred to, would make in our results over the last forty years, if these various alterations were adopted throughout in the records and estimates of the past, as it is proposed they shall be in those of the future.

Appendix-Table II. (facing p. 58) gives, in precisely the same form as in Appendix-Table I. (p. 58), the results for the forty years as to the estimated home produce, the amount of it available for consumption, the imports, the total available supply, the population, and the amounts available per head per annum; but with the home produce, both per acre and aggregate, and the

imports, reckoned at 60 lb. per bushel instead of, as formerly, the home at 61 lb. and the foreign at 60⅔ lb. per bushel; also reckoning 72 parts "wheat-meal and flour," instead of, as formerly, 80·77, or 80 to correspond to 100 of wheat; and lastly with the corrected population. It also shows the percentage of the total available supply from home and foreign sources respectively.

Appendix-Table II. further shows the average *Gazette* price of the home wheat per quarter; and the calculated price per quarter of the imported wheat, according to the *Trade and Navigation Returns*, as will be explained farther on, for each harvest-year; the aggregate value of the wheat available within each harvest-year, both home and imported; also the aggregate value of the wheat estimated to be required, and the value per head, each year.

Before referring to the general and very important indications of this very comprehensive Table, it will be well to discuss the influence, on the results, of the several individual alterations adopted in it.

First as to the population:—The basis of the corrections subsequently adopted by the Registrar-General has already been explained (p. 4). It would serve little useful purpose to take up space by showing the corrections for each individual year, but a comparison of the columns showing the population each year, in the Appendix-Table I. uncorrected, and in the Appendix-Table II. corrected, will supply detailed information on the point. It will suffice here to point out the direction and range of the alterations over the several periods.

In the intercensal years from 1861 to 1871, and from 1871 to 1881, there is a progressively increasing addition made from the first to the last year from census to census in each case. This ranges over the first of the two intercensal periods, from between 2,000 and 3,000 in the first, to more than 400,000 in the last year of the ten; and over the second of these periods of ten years each, from about 26,000 in the first to about 18,000 in the last of the ten years. On the other hand, from 1881 to 1890 inclusive, there is, instead of an addition, a reduction in a greater proportion than the former additions. The reduction ranges from about 72,000 in 1882, to nearly 740,000 in 1890.

These statements relate to the returns of the Registrar-General, given for the middle of the year, that is, for the end of June in each case. But it is to be borne in mind that, in our Tables, the figures are given, not for the middle of the civil, but of the harvest-year; that is, for the end of February. The effects of the corrections above referred to on our eight-yearly periods of harvest-years are as follows:—Over the eight-

yearly period, 1852–3 to 1859–60, no alteration is made. Over the second period, from 1860–1 to 1867–8, with an average population of between 29 and 30 millions, the corrections show a progressively higher population than the original returns, ranging from under 2,000 in the first, to nearly 300,000 in the last of the eight harvest-years, and an average annual addition of about 132,000. Over the third period, 1868–9 to 1875–6, there is still a progressively increasing addition, amounting to about 400,000 in the second harvest-year; and then, after the census of 1871, there is at first a comparatively small increase, which only reached about 105,000 in the eighth year. Over the whole period of eight years, with an average population of nearly 32,000,000, the average annual increase, according to the amended as compared with the original returns, amounts to about 156,000. Over the fourth period, from 1876–7 to 1883–4, there is some increase over the five years up to the census of 1881, and afterwards, that is, over the last three years of the period, a greater annual reduction; the result being that, with an average population of rather more than 34,500,000, the corrections add an average annual number of less than 12,000. Lastly, over the last eight years, 1884–5 to 1891–2, there is, up to the census of 1891, a considerable deduction to be made from the earlier returns, amounting to more than 700,000 in 1889–90; but afterwards the reduction is quite insignificant. The general result, so far as this last eight-yearly period is concerned, is that, with an average population of about 37,000,000, the corrected figures, compared with the earlier, show an average annual reduction of about 370,000.

Taking the results for the forty years, the corrections in the direction of increase are so far compensated by those in the direction of reduction, that over the whole period they indicate an average annual reduction which amounts to only about 14,000. It will not be surprising, therefore, that although the uncorrected and the corrected figures for the population show some slight difference in the calculated amount of wheat available for consumption per head over individual periods, they make none whatever when the average is taken over the forty years. This is illustrated in Table III. on the opposite page.

It should be understood that the figures in the Table (III.) relate to the amounts of wheat available as recorded in Appendix-Table I. (p. 58), that is, without any alteration from the hitherto adopted relation of imported flour to wheat, and weights per bushel of 61 lb. for home, and of 60¾ lb. for foreign wheat. Indeed, the figures in the first column are precisely the same

as those given in Table II. (p. 23); and those in the second are only altered in accordance with the corrected number of the population. It will be seen that whilst over the first and fourth periods the two columns show identical amounts, over

TABLE III.

	Total wheat available for consumption per head	
	Calculated on population as formerly given	Calculated on corrected population
	Bushels	Bushels
Averages for:—		
8 years 1852–3 to 1859–60 .	5·07	5·07
8 „ 1860–1 „ 1867–8 .	5·49	5·47
8 „ 1868–9 „ 1875–6 .	5·59	5·56
8 „ 1876–7 „ 1883–4 .	5·66	5·66
8 „ 1884–5 „ 1891–2 .	5·66	5·72
40 „ 1852–3 „ 1891–2 .	5·50	5·50

the second and third periods, the second (corrected) shows slightly lower figures, and over the fifth period the second column shows a slightly higher amount. The two calculations show, however, absolutely identical amounts reckoned over the total period of forty years.

The next point to consider is the effect, upon our past estimates, of the amount of wheat available for consumption, of the altered relation recently adopted by the Boards of Trade, Customs, and Agriculture, in calculating the imported "wheat-meal and flour" into their equivalent of wheat.

We have been informed that wheat imported as wheat and returned in cwts. was, until recently, converted into quarters by multiplying the cwts. by 8 and dividing by 13. This gives the weight of the quarter = 485⅓ lb., corresponding to 60⅝ lb. per bushel. Throughout the period of our inquiry, we have frequently checked the relation between the official returns of imported wheat in cwts. and its recorded equivalent in quarters, and we have always found it to be that above stated. Wheat imported as wheat has, therefore, been recorded in quarters of 60⅝ lb. per bushel.

Then as to the calculation of imported "wheat-meal and flour" into its equivalent of wheat. In Vol. VI. of Tooke and Newmarch's *History of Prices*, published in 1857, they say (pp. 466–7), that "flour" returned in cwts. is calculated into imperial quarters of wheat at the rate of 3½ cwts. of flour from

a quarter of wheat. Now, taking 3½ cwts. of flour=392 lb., and a quarter of wheat at the so long adopted weight of 60⅔ lb. per bushel=485⅓ lb. per quarter, the relation is 100 of wheat for 80·77 flour. This is exactly the relation which we find to hold good in the official returns of flour in cwts., and its equivalent in quarters of wheat, for about the latter half of the period of our inquiry; but, at any rate in some of the previous years, the relation has been 80 parts of flour to 100 of wheat, instead of 80·77 to 100. Indeed, it is stated at the head of the Tables in some of the numbers of the *Statistical Abstract* that 1 cwt. of imported flour is reckoned as equivalent to 1¼ cwt. of wheat; and when the returns are so given, we have, for the purposes of our estimates, calculated the cwts. of wheat so obtained into quarters of 488 lb., corresponding to 61 lb. per bushel. It makes, in fact, comparatively little difference in the number of quarters of wheat, whether flour is reckoned into wheat at the rate of 80·77 flour to 100 wheat, and the wheat in quarters of 485⅓ lb.=60⅔ lb. per bushel, or whether 80 flour to 100 wheat, and quarters of 488 lb.=61 lb. per bushel, be adopted.

Such were the relations adopted in the official returns of imported wheat, and of imported "wheat-meal and flour," in the conversion and representation of them in quarters of wheat up to 1890 inclusive. Commencing with 1891, however, wheat has been reckoned in quarters of 60 lb. per bushel=480 lb. per quarter, and 72 instead of 80·77 parts by weight of imported flour have been reckoned as equivalent to 100 of wheat. Further, it is, we are informed, proposed to correct the figures which relate to 1890 and 1889 in future issues of the accounts upon the same basis; and also, in summarising the imports of wheat and flour as wheat for a series of fifteen years, as is annually done in the *Statistical Abstract for the United Kingdom*, to raise the equivalent 1 per cent. each year, for the nine years 1888 to 1880 inclusive; thus, in 1888, 73 flour for 100 wheat will be taken, in 1887, 74 flour, and so on, until in 1880 the old figure of 80·77 is reached; but earlier than this no change will be made.

The question obviously arises—how far the necessity for the change is due to corresponding real differences in the yield of flour obtained in the earlier and in the later years? It is quite certain that 80·77 parts by weight of ordinary bread-flour have not been obtained from 100 of wheat; and as in the official returns of the Board of Trade the imports have generally been designated as "Wheat-meal and Flour," the question is suggested whether any material quantity of *wheat-meal* properly so called—that is, simply the ground grain, of which the latter

would of course yield cent. per cent., less the small loss in grinding—be included. On this point we are informed that the imports of wheat-meal are quite insignificant. The question still remains—whether the imports included any large proportion of flour of lower grades, or of pollards? Here, again, we are informed that pollards are returned as such, and not included under the designation of flour. Then it is to be observed that, so long ago as 1857, Tooke and Newmarch designated the imports as "flour," and gave the relation of 3½ cwt. of flour to a quarter of wheat as the basis of the conversion; and, as has been seen, this relation has substantially been adopted up till quite recent years.

Upon the whole, therefore, we conclude that the change recently adopted is a real correction of an estimate, dating from the time of the first adoption of the rough and ready reckoning of 3½ cwt. of flour to a quarter of wheat. We think, however, that 72 for 100 of wheat is probably somewhat too low for the average of imported flours; and that at any rate 73, if not even a rather higher figure, would probably better represent the relation in the case of imported flours. That English millers consider the figure 72 too high, judged by the yield in this country, seems irrelevant to the present question, which has reference to imported flour alone. About three-fourths of the flour imported into the United Kingdom come from the United States, and from our own inquiries we are led to believe that, both at Minneapolis and at San Francisco, the yield of barrelled flour for export is certainly not less than 72 from 100 of wheat. Then about 10 per cent. of our imports come from Austrian territories, and the average yield there is probably at least 74 parts of flour from 100 of wheat.

Under all the circumstances, therefore, we have decided that if in our revised Table we assume the now adopted figure of 72 flour for 100 wheat as applying to the returns of imported wheat flour from the period of the commencement of our inquiry, namely, the harvest-year 1852–3, for the whole forty years ending 1891–2, we shall probably bring the figures more nearly into harmony with the actual facts, than by adopting any compromise or partial scheme founded on probably more uncertain data. A further reason in favour of the plan proposed is that, as will be seen presently, the amount of wheat represented by imported flour bears but an insignificant proportion to the whole quantity available from all sources in the earlier years, and a gradually increasing one up to the present time. The consequent alteration in the records for each individual year of the forty will be seen on comparing the uncorrected results given in

Appendix-Table I. (p. 58), with the corrected ones in Appendix-Table II. (facing p. 58).

The following Table (IV.) summarises, for each eight-yearly period, and for the forty years, the effect on the results of adopting throughout, 72 flour for 100 wheat, instead of, as formerly, taking 3½ cwt. flour to a quarter of wheat, corresponding to 80·77 flour to 100 wheat. The first column shows the average amount of wheat per annum for each period, due to imported flour on the old calculation, and the second column corresponding results on the new basis. The right-hand division of the Table shows—in the first column the total available supplies of wheat, home and foreign together, with the imported flour reckoned according to the old factor; in the second column the same, but with imported flour reckoned into wheat by the new factor; and in the last column the difference. In all cases the imported wheat is reckoned in quarters of 485⅓ lb., which correspond to 60⅔ lb. per bushel.

TABLE IV.

	Imported wheat-meal and flour, as wheat		Total available wheat, home and imported		
	3½ cwt. wheat flour = 1 qr. wheat; or 80·77 to 100	72 flour to 100 wheat	3½ cwt. wheat flour = 1 qr. wheat; or 80·77 to 100	72 flour to 100 wheat	New calculations + or − old
Averages for :—	Quarters	Quarters	Quarters	Quarters	Quarters
8 years 1852–3 to 1859–60 . . .	928,900	1,042,035	17,814,000	17,927,135	+113,135
8 „ 1860–1 „ 1867–8 . . .	1,404,657	1,575,738	20,301,099	20,472,180	+171,081
8 „ 1868–9 „ 1875–6 . . .	1,434,758	1,609,504	22,219,508	22,394,254	+174,746
8 „ 1876–7 „ 1883–4 . . .	3,139,864	3,522,272	24,499,335	24,881,753	+382,418
8 „ 1884–5 „ 1891–2 . . .	4,630,006	5,193,917	26,438,261	27,002,172	+563,911
40 „ 1852–3 „ 1891–2 . . .	2,307,635	2,588,693	22,254,441	22,535,499	+281,058

The first two columns show that, over the first eight years, 1852–3 to 1859–60, the amount of wheat due to imported flour was less than 1,000,000 quarters; during the next two eight-yearly periods it rose to about 1½ million quarters; during the fourth period to considerably over 3,000,000, or more than twice as much as formerly, and over the last eight years to about 5,000,000 quarters, or about 1½ time as much as over the immediately preceding eight years. Lastly, the average per annum over the total period of forty years has corresponded to rather under 2⅓ million quarters according to the old, and to over 2½ million quarters according to the new calculation.

Turning to the results given in the last three columns of the Table, we there see the influence of the alteration on the estimate of the total available annual supply of wheat from all sources; the last column showing the increase over the former estimates of the supply, on the assumption that the new calculations more nearly represent the truth. It will be seen that the change represents an annual increase of supply over former reckonings of about 113,000 quarters over the first eight years, of about 171,000 over the second, of nearly 175,000 over the third, of more than 382,000 over the fourth, and of nearly 564,000 over the fifth eight-yearly period. Large as these amounts seem, especially in the later periods, it is satisfactory to know that they represent an increase in the total supply of only about 0·64 per cent. over the first eight years, 0·84 per cent. over the second, 0·79 per cent. over the third, 1·56 over the fourth, and 2·13 per cent. over the fifth eight-yearly period; whilst over the forty years they represent a difference of only 1·26 per cent.

Nevertheless, these quantities do represent a veritable and not immaterial amendment of the former estimates. The effect of the adoption of the change on our previous estimates of the average annual consumption of wheat per head of the population is brought to view in Table V. The first column shows our annually adopted estimates of the consumption per head; and the remaining columns the amounts available per head. The second column shows the amounts of the total available, derived from the home produce; the third and fourth the amounts derived from imports, according to the old and the new calculation

TABLE V.

—	Adopted average consumption per head	Available for consumption per head					
		From home produce	From imports		Total from home produce and imports		
			80·77 flour to 100 wheat	72 flour to 100 wheat	80·77 flour to 100 wheat	72 flour to 100 wheat	New results + or − old
	Bushels	Bushels	Bushels	Bushels	Bushels	Bushels	Bushels
Averages for:—							
8 yrs. 1852–3 to 1859–60	5·10	3·74	1·33	1·36	5·07	5·10	+0·03
8 „ 1860–1 „ 1867–8	5·50	3·31	2·18	2·23	5·49	5·54	+0·05
8 „ 1868–9 „ 1875–6	5·60	2·93	2·66	2·70	5·59	5·63	+0·04
8 „ 1876–7 „ 1883–4	5·65	2·03	3·63	3·71	5·66	5·74	+0·08
8 „ 1884–5 „ 1891–2	5·65	1·83	3·83	3·95	5·66	5·78	+0·12
40 „ 1852–3 „ 1891–2	5·50	2·77	2·73	2·79	5·50	5·56	+0·06

respectively; and the fifth and six columns the total amounts available per head from home and foreign sources together, also respectively, according to the old and the new calculations; and the last column shows the increase in the available total supply per head per annum, according to the new as compared with the old calculations.

In the first place it is to be observed, that the estimates of the average amounts available per head over the different periods from home produce, are, of course, in no way affected by the alteration in the calculation of the imports. It is seen, however, comparing the third and fourth columns, that there is, over each period, a slight increase in the estimated amount of the supplies from foreign sources, due to the alteration in the calculation of the amount of wheat corresponding to the imports of flour. There is necessarily the same amount of increase shown on comparing the fifth and six columns, which represent the total quantities annually available per head over each period, according to the old and the new calculation respectively. The actual amount of increase indicated as due to the new mode of estimate is shown in the last column. It is seen to be small over the first, second, and third periods, but greater over the fourth, and greater still over the fifth, amounting then to 0·12 bushel per head per annum.

On this point it may be observed, that the annually adopted estimates for the last eight-yearly period show an average annual requirement of 5·65 bushels, whilst the amount calculated from the available supplies of home and foreign wheat, and the population, show, for the same period, according to the old calculation, 5·66, and according to the new 5·78 bushels per head. It may be of interest to state, however, that an increase in the consumption of 0·12 bushel per head on a population of about 37 millions, which was approximately the average for the period, represents an increase in the annual requirement of about 564,000 quarters on the previously estimated amount of nearly 26,500,000 quarters.

It will be obvious that the change in the estimates of the total amount of wheat annually available for consumption, and of the annual consumption per head accordingly, in no way vitiates the significance of the accordance of the estimates of consumption and of requirement hitherto annually made, with the amounts subsequently recorded as available. But it will be equally obvious that it implies a real change, not only in the figures previously adopted, but in the actual quantities they represent on the two points. It is to be borne in mind that in all the foregoing summary Tables, the old reckoning of 61 lb.

per bushel for home produce, and of 60⅝ lb. per bushel for imported wheat, are adopted; and the last two summary Tables (IV. and V.) indicate the extent of the change expressed in quarters, or bushels, of the above-mentioned weights per bushel. The amounts so expressed, of course, represent a real increase, both in the aggregate quantities available, and in the consumption per head, compared with those previously assumed. On the other hand, although the adoption for the past, as in the Appendix-Table II. (facing p. 58), and in all future estimates as we propose, of a uniform weight of 60 lb. per bushel, both for home and for foreign wheat, will materially alter the figures, the alteration so made will not represent any change in actual quantity.

The Results for the Forty Years, according to the recently adopted Standards or Corrections.

We have now discussed the influence, on our former estimates, of corrections made by the Registrar-General of the originally recorded numbers of the population, and it has been shown to be comparatively immaterial. We have also considered the influence on the past estimates, of the change adopted by the Departments, in the calculation of imported flour into its equivalent of wheat, and this has been found to involve, though a comparatively small, yet by no means an immaterial, correction. We propose now to apply the weight of 60 lb. per bushel to the whole of the estimates for the past forty years, an alteration which, as we have pointed out, involves no change in actual quantity, but only in the mode of representation; and it is from the results as so calculated, that we shall draw illustrations as to the bearing and the importance of the facts which the inquiry, extended over so long a period, brings to light. We shall also point out what changes will be adopted in future estimates.

As already intimated, the Appendix-Table II. (facing p. 58) gives the whole of the results for the forty years, embodying the corrections in the number of the population which have been referred to, those due to the altered estimate of the relation of flour to wheat, and, lastly, adopting a weight of 60 lb. per bushel for both the home produce and the imported wheat. For the details the reader is referred to the Table itself; but, as in the discussion of the various points hitherto, the bearing of the various results will be founded on summaries from the detailed Table, which will be embodied in the text.

Area under Wheat in the United Kingdom.

The following Table (VI.) shows the average area under the crop in the United Kingdom for each of the five eight-yearly periods, and for the total period of forty years.

TABLE VI.

	Average area under wheat in the United Kingdom	Increase or decrease over each period of 8 years
	Acres	Acres
Averages for:—		
8 years 1852–3 to 1859–60.	4,092,160	
8 „ 1860–1 „ 1867–8 .	3,753,011	−339,149
8 „ 1868–9 „ 1875–6 .	3,788,132	+ 35,121
8 „ 1876–7 „ 1883–4 .	3,091,310	−696,822
8 „ 1884–5 „ 1891–2 .	2,512,924	−578,386
40 „ 1852–3 „ 1891–2 .	3,447,507	—

This summary Table is sufficient to bring clearly to view the very great decline that has taken place in the area under the crop during the forty years. But the better to understand the causes of it, it is necessary not only to study the figures for the individual years, but to consider them in connection with the acreage yield of the crop, the imports, and the average price of wheat. Speaking generally, it will be found that a good yield, or relatively high price, has tended to check reduction, whilst contrary conditions in these respects have had the effect of accelerating it. It has been explained at pp. 5–6, that over the first fourteen years of the forty, the area was to a great extent estimated only, but that from 1866 up to the present time official returns have annually been available. These circumstances must, of course, be borne in mind, and must prevent too rigid an interpretation of the exact figures. Still, having regard to the unusually high yields per acre in 1863, 1864, and 1865, and the consequent reduction in price, there is no reason to doubt that the reduction of area over the second eight-yearly period, including these years, which the figures indicate, substantially represented the truth. The recovery in the area over the third period of eight years, especially in the first and second years, 1868–9 and 1869–70, is obviously a natural consequence of the higher price over the two preceding harvest-years; whilst the general, though slight, increase throughout the period is accompanied with fair maintenance of price up to nearly the end of it.

As the summary shows, it is over the fourth and fifth periods that the very great decline has taken place, and it is over these that the very marked decline in price prevailed. Further, it was within the fourth period that the disastrous harvest of 1879 occurred, not only in the United Kingdom, but in Western Europe generally. This led to some increase in price, and to greatly increased imports, which, with the exception of one or two years, have steadily increased ever since. In fact, it was the very bad season of 1879, succeeded by several of less than average yield, that led to the great extension of exporting areas in different parts of the world, and coincidently to a great reduction in price; and, with this, to a great reduction of area under the crop in the United Kingdom. Assuming the estimates of area in the earlier years to be approximately correct, it would appear that it has been reduced from rather more than 4,000,000 acres over the first eight years, to little more than 2,500,000 over the last eight, to 1891 inclusive; whilst, in 1892, it was not quite 2,300,000 acres.

Average Yield of Wheat per Acre in the United Kingdom.

Table VII. shows the average yield of wheat per acre over each eight-yearly period, and over the forty years, according to our annually adopted estimates of the crop. The first column shows the results reckoned in bushels of 61 lb., as we have always hitherto given them, and the second in bushels of 60 lb., as given in Appendix-Table II., and as it is proposed in future to represent them.

TABLE VII.

	Average yield of wheat per acre	
	Bushels of 61 lb.	Bushels of 60 lb.
Averages for:—	Bushels	Bushels
8 years 1852 to 1859 . .	28	28 3/8
8 „ 1860 „ 1867 . .	28 3/8	28 7/8
8 „ 1868 „ 1875 . .	26 1/2	27 1/8
8 „ 1876 „ 1883 . .	24 7/8	25 1/4
8 „ 1884 „ 1891 . .	29 1/8	29 7/8
40 „ 1852 „ 1891 . .	27 1/2	27 7/8

Here, again, we must refer to the Appendix-Tables I. and II. for the yield of individual years. Referring to the summaries as in Table VII., it is seen that the first two eight-yearly periods show

fairly uniform average amounts; the second, however, rather more than the first. The third period gives considerably less, the fourth less still, and the fifth period, 1884–91, inclusive, considerably the highest of the five. Directing attention first to the estimates as formerly given, that is, at 61 lb. per bushel, it is seen that the average of the first two eight-yearly periods indicates somewhat more than 28 bushels per annum; and up to comparatively recent years we reckoned the general average yield of the United Kingdom at 28¼ bushels. The third and fourth periods taken together show, however, an average of scarcely 25⅞ bushels. The fifth period, on the other hand, shows an average of 29⅜ bushels, or one bushel higher than even the highest of either of the preceding eight-yearly periods.

The fact is, that within the fifth eight-yearly period there was only one year with an estimated yield of less than 28 bushels; whilst the second eight-yearly period, which gives the next highest average, although it included two years, 1863 and 1864, of the highest yield of the forty, and two others of more than average yield, at the same time included four years of considerably less than average. There can, indeed, be no doubt, that the eight years commencing with 1884 and ending with 1891 gave a higher average yield of wheat per acre than any equal period of the forty years. Notwithstanding this, however, with the very low average yields over the third and fourth periods, the average of the forty years shows only 27½ bushels at 61 lb. per bushel, against rather more than 28 assumed to be the general average of the country over the early years. Of course, reckoned at 60 lb. per bushel, the figures are so much higher; but, even so reckoned, the average yield of the forty years is only 27⅛ bushels, that is, less than 28 as formerly assumed, whilst the average yield of the last eight years, 1884–91 inclusive, is 29⅛ bushels, or 2 bushels more than the average of the forty years, and 2½ bushels more than over the preceding thirty-two years.

The Aggregate Home Crop, and the Amount of it available for Consumption.

The next Table (VIII.) shows, for each of the eight-yearly periods, and for the forty years, the average annual total home produce, calculated from the recorded area under the crop, and the estimated average yield per acre; also the amount of it estimated to be available for consumption, after deducting from the total the amount assumed to be required for seed. The first two columns show the so-reckoned total and available

amounts reckoned at 61 lb. per bushel, as formerly, and the last two in each case at 60 lb. per bushel. For the first thirty-five of the forty years, 2¼ bushels per acre on the acreage of the year have been deducted from the total home crop for the seed of the next year, but for the last five years only 2 bushels per acre. It is, of course, not assumed that there was a sudden change at that period; but, believing that a gradual reduction has taken place, it was at that date, that is, first for the crop of 1887, decided to reduce the amount then and for the future.

TABLE VIII.

	Home produce of wheat			
	At 61 lb. per bushel		At 60 lb. per bushel	
	Total	Available for consumption	Total	Available for consumption
	Quarters	Quarters	Quarters	Quarters
Averages for:—				
8 years 1852 to 1859 . .	14,310,779	13,159,859	14,554,230	13,403,310
8 „ 1860 „ 1867 . .	13,309,247	12,253,712	13,523,034	12,467,499
8 „ 1868 „ 1875 . .	12,684,765	11,619,353	12,900,291	11,834,879
8 „ 1876 „ 1883 . .	9,636,682	8,754,751	9,793,979	8,922,986
8 „ 1884 „ 1891 . .	9,208,029	8,549,916	9,365,087	8,706,974
40 „ 1852 „ 1891 . .	11,829,900	10,867,518	12,027,324	11,067,130

The figures show an average annual reduction in the total home-crop of about 1,000,000 quarters over the second period compared with the first, about two-thirds of a million over the third compared with the second, more than 3,000,000 quarters over the fourth compared with the third, but less than half a million over the last compared with the fourth. Of course these reductions in the aggregate produce of the country are largely due to the reduction in area under the crop, but they are also largely dependent on the difference in the average yield per acre over the different periods. Thus, with a fully equal—indeed, the figures show a slightly higher—estimated area over the third period compared with the second, there is nevertheless a considerable relative deficiency in the aggregate produce of the third period, due to an average reduction of 1⅛ bushel in the yield per acre. Then, comparing the fourth with the third period, there is a greater average reduction in area than in any other case, but there is at the same time a reduced yield per acre of 1⅛ bushel; and it is these two conditions combined that result in the reduction of more than 3,000,000 quarters per annum in the aggregate produce over the fourth

period. Lastly, though over the fifth eight-yearly period there is, compared with the fourth, a very large average annual reduction of area under the crop, amounting to more than half a million acres, there is, at the same time, an increase of 4½ bushels in the average yield per acre per annum; and, with this, there is a reduction of less than half a million quarters over the fifth period compared with the fourth, instead of more than 3,000,000 quarters under contrary conditions as to yield per acre over the fourth compared with the third period.

Not only is there the great reduction in the aggregate yield of the home-crop which the figures in Table VIII. show, but examination of the results for the individual years, as given in Appendix-Tables I. and II., show that sometimes during the earlier years the home produce was twice as much as in some of the individual later years.

Comparing column with column in Table VIII, it is seen that reckoning the produce at 60 lb. instead of at 61 lb. per bushel, raises the number of quarters by which an equal weight of grain is represented by about 200,000 per annum on a total quantity of about 12,000,000 quarters, or by about 1⅔ per cent. Next, comparing the amounts estimated to be available for consumption, deducting from the total the requirement for seed, it is seen that over the first three periods the reduction represents an average of more than one million quarters per annum, over the fourth period with its much reduced area, yield, and aggregate produce, less than one million quarters, over the fifth period with the still further reduction of area and total produce, and of course still less deduction per acre for seed, only about two-thirds of a million; but, over the forty years, an average of nearly one million quarters per acre per annum.

The figures further show that the average annual amounts available for consumption from the home-crop were only about two-thirds as much over the last sixteen as over the first sixteen of the forty years. What this reduced actual supply of wheat available for consumption from the home-crop represents, when considered in connection with the coincident increase of population, and therefore of requirement, will be seen farther on.

The Imports of Wheat, and of Flour reckoned as Wheat.

In the discussion of Table IV. (p. 30 and context), we have shown the actual increase in the amount of wheat available from imported flour, due to adopting, as we now do, the relation of 72 flour to 100 wheat, instead of 80·77 to 100 as formerly; and we have pointed out to what extent this change increases

the estimate of the total supply annually available for consumption from all sources, home and foreign; and we must refer the reader to that Table and discussion for further particulars on these points. Adopting now the new mode of computation, Table IX., below, shows the average annual net imports (imports less exports) of wheat and of flour reckoned as wheat, over each of the eight-yearly periods, and over the forty years. The quantities are, however, given both in quarters reckoned at 60⅔ lb. per bushel as formerly for imported wheat, and at 60 lb. per bushel as now adopted.

TABLE IX.

—	Net imports of wheat, and of flour reckoned as wheat (72 flour = 100 wheat)		
	At 60⅔ lb. per bushel	At 60 lb. per bushel	Increased number at 60 lb.
	Quarters	Quarters	Quarters
Averages for :—			
8 years 1852-3 to 1859–60 .	4,767,276	4,820,246	+ 52,970
8 „ 1860–1 „ 1867–8 . .	8,218,468	8,309,783	+ 91,315
8 „ 1868–9 „ 1875–6 . .	10,774,901	10,894,622	+ 119,721
8 „ 1876–7 „ 1883–4 . .	16,127,002	16,306,191	+ 179,189
8 „ 1884–5 „ 1891–2 . .	18,452,256	18,657,281	+ 205,025
40 „ 1852–3 „ 1891–2 . .	11,667,980	11,797,625	+ 129,645

Unlike the change in the adopted relation of flour to wheat, which, as has been pointed out, causes a real and not immaterial increase in the estimate of the amount of wheat available for consumption, the change in the figures due to reckoning the quantities at only 60 lb., instead of 60⅔ lb. per bushel, does not represent any increase in actual quantity by weight; but only a larger number of quarters of less weight per quarter, as shown in the last column of the Table. The actual increase in the number of quarters at the lower weight per bushel is seen to be comparatively small over the earlier periods, when both the total quantity of the imports, and the proportion of them due to flour, were small. It may be observed that the increase in measure, by adopting the lower weight per bushel, represents about 1½ per cent. on the quantities at the higher weight.

Let us now turn to the more important indications of the Table. When considering the home-crop, it was pointed out that its aggregate produce was only about two-thirds as much over the later as over the earlier periods. The Table now under consideration shows that the imports were, on the other hand,

not far short of four times as great over the last as over the first of the five eight-yearly periods. It is seen that the annual imports averaged about 4¾ million quarters over the first eight years; that they increased by nearly 3½ million quarters over the second eight, by more than 2½ million over the third eight, by about 5½ million over the fourth eight, and by nearly 2½ million quarters over the last eight years. It will be thus seen that by far the greatest rate of increase in the imports was over the fourth period from 1876–7 to 1883–4 inclusive. The fact is, that in four out of the last five years of the third period, the yield per acre of the home crop was very low; and that in six out of the eight years of the fourth period the yield was below the average, and in 1879 it was extremely low; the result being a lower average yield per acre over this than over either of the other eight-yearly periods; and, as we pointed out in our paper on *Allotments and Small Holdings*, in a recent number of this Journal (Vol. III., 3rd Series, Part III., 1892), the series of unproductive seasons, not only in our own country but in Western Europe generally, led concurrently to the opening up of large wheat-growing areas in various parts of the world, to greatly increased imports, and at the same time to much lower prices.

The significance of the very great and rapid increase in the imports of this staple article of the food of the population of the United Kingdom, which the figures in the Table (IX.) bring to light, will be better appreciated when we come to consider, in the next section, the proportion which the imported wheat bears to the total amount available for consumption; and farther on, the proportion which the value of the imports bears to the total value of the wheat consumed.

Total Wheat (Home and Imported) available for Consumption.

The following Table (X.) shows, for each of the five eight-yearly periods, and for the forty years, the average annual amount of wheat available for consumption from home and foreign sources taken together, reckoning 72 of imported flour to represent 100 of wheat, and the whole taken at the newly adopted weight of 60 lb. per bushel. The first column shows the average annual amounts in quarters so reckoned, and the second and third columns show the percentage of the total derived from home and from foreign sources respectively.

The figures in the first column show that the average annual aggregate amount of wheat available for consumption in the United Kingdom was almost exactly one-and-a-half time as much over the last eight as over the first eight of the forty years.

It will be seen further on, that the amount available per head of the population has somewhat increased over the later as compared with the earlier periods, but in only a small degree

TABLE X.

—	Average annual total wheat available for consumption, home and imported		
	72 flour=100 wheat, 60 lb. per bushel	Per cent. of total	
		From home produce	From imports
	Quarters	Per cent.	Per cent.
Averages for:—			
8 years 1852–3 to 1859–60 .	18,223,556	73·1	26·9
8 „ 1860–1 „ 1867–8 . .	20,777,282	59·5	40·5
8 „ 1868–9 „ 1875–6 . .	22,729,501	52·0	48·0
8 „ 1876-7 „ 1883–4 . .	25,229,177	35·3	64·7
8 „ 1884–5 „ 1891–2 . .	27,364,255	31·9	68·1
40 „ 1852–3 „ 1891–2 . .	22,864,754	50·4	49·6

compared with the great increase in the aggregate consumption; which, as will be seen presently, is mainly due to the rapid increase in the population.

The last two columns of the Table show in what proportion the increased demand has been met from home and from foreign sources respectively. Thus, whilst over the first eight-yearly period the home producer provided about 73 per cent. of the total requirement, over the last eight years he provided only about 32 per cent. In other words, over the earlier period he provided nearly three-fourths, but over the later less than one-third of the total requirement. On the other hand, whilst over the first eight years imports supplied only about 27 per cent., over the last eight they supplied about 68 per cent. of the requirement, or more than two-and-a-half times the proportion of the total over the last than over the first eight years; in fact, little more than one-quarter of the total over the first period, but more than two-thirds of the total over the last period. This was the case, notwithstanding that the last eight-yearly period gave a higher average yield per acre of the home-crop than either of the four preceding periods. The truth is, that the less dependence on home, and the greater on foreign supplies, has been largely due to the increase of the population overcoming our capability of production; but, of course, largely also to the reduction of area under the crop at home as a consequence of greatly increased production for export in other countries, and coincidently great increase in our imports, and great reduction in price.

The Population, and the Requirement of Wheat per Head per Annum.

Table XI. shows the average population for each of the eight-yearly periods, and for the total period of forty years, according to the corrected returns. The next three columns show, for comparison with the newly adopted results given in the last column—in the first the previously adopted estimates of annual requirement per head, assuming 80·77 imported flour to 100 wheat, and wheat at 61 lb. per bushel; and in the second and third columns the amounts available per head on the assumption of the same relation of flour to wheat, but in the second reckoning home wheat at 61 lb. and foreign at 60⅔ lb. per bushel as hitherto, and in the third, for better comparison with the new results, taking both home and foreign at 60 lb. per bushel. The last column shows the total amounts available per head per annum from home and foreign sources together, on the assumption of 72 flour = 100 wheat, and taking wheat at 60 lb. per bushel.

TABLE XI.

—	Population	Previously estimated requirement per head, 80·77 flour = 100 wheat; wheat 61 lb. per bushel	Total available per head		
			80·77 flour = 100 wheat		72 flour = 100 wheat; wheat 60 lb. per bushel
			Home 61 lb. imported 60⅔ lb. per bushel	Home and imported 60 lb. per bushel	
		Bushels	Bushels	Bushels	Bushels
Averages for :—					
8 years 1852–3 to 1859–60	28,067,170	5·10	5·07	5·16	5·19
8 „ 1860–1 „ 1867–8	29,738,375	5·50	5·47	5·55	5·60
8 „ 1868–9 „ 1875–6	31,943,230	5·60	5·56	5·65	5·69
8 „ 1876–7 „ 1883–4	34,615,019	5·65	5·66	5·74	5·83
8 „ 1884–5 „ 1891–2	36,950,178	5·65	5·72	5·83	5·92
40 „ 1852–3 „ 1891–2	32,262,794	5·50	5·50	5·59	5·65

The first column of the Table (XI.) brings strikingly to view the rapid increase of the population in the United Kingdom during the last forty years. Comparing each eight-yearly period with the one preceding it, there was an increase over the second eight years of about 1⅔ million; over the third period of nearly 2¼ millions; over the fourth of 2⅔ millions; and over the fifth of 2⅓ millions; that is to say, the progression was the most rapid during the fourth period, and somewhat less over the

fifth. Comparing the first eight years with the fifth eight, the latter shows an increase from 28 to nearly 37 millions, or by nearly 9 millions, corresponding to nearly one-third more over the last period compared with the first. No wonder, then, at the great increase in the aggregate supplies of wheat over the later as compared with the earlier periods, as shown in the last section. The increase in the supply from period to period as there shown has, however, to meet the demand, not only of an increased number of consumers, but also a slightly larger requirement per head over the later periods.

Comparing the last column with the one before it, both being reckoned at 60 lb. per bushel, it will be seen to what extent the actual available supply per head per annum is increased over the respective periods, by raising the estimate of the amount of wheat corresponding to a given amount of flour. It has already been shown that the previously annually adopted estimate of the requirement per head, which was modified from time to time according to the subsequently ascertained available supplies, agreed extremely closely with the amounts of those supplies when averaged over a series of years so as to eliminate the disturbing influence of stocks on hand; and it is obvious that it could not be otherwise, if the annual estimates were judiciously modified according to the previously actually ascertained supplies. But now that the past supplies are assumed to have been in reality greater than the previously adopted figures represented, it is obvious that the estimate of the available supply per head must also be correspondingly increased. To add to this, the quantities are now represented in bushels of only 60 lb., so further raising the figure, but not the amount represented by it.

A comparison of the first and second columns, relating to the quantities per head, will show how very closely the annual estimates of requirement and the amounts afterwards proved to be available agreed, the two being taken at approximately the same weight per bushel. The third column gives the same results as the second, but reckoned at only 60 lb. per bushel, and shows, therefore, higher quantities by measure available; and, compared with these, the higher amounts in the last column show the increase in the amount available per head, due to assuming a given amount of imported flour to represent a greater quantity of wheat. It is these last quantities that we now adopt, as representing the annual requirement per head, in accordance with the actual amounts annually available from all sources—home and foreign.

It will be seen that the previously adopted estimate of require-

ment per head for the last two eight-yearly periods was 5·65 bushels at 61 lb. per bushel; that the amount actually available over the first of these two periods was 5·66, and over the second 5·72 bushels at approximately the same weight, and 5·74 and 5·83 bushels at 60 lb. per bushel. But the new reckoning shows an available supply of 5·83 bushels over the fourth, and 5·92 bushels over the fifth period, at 60 lb. per bushel. The question arises, therefore, whether the actual figure indicated for the last period, namely 5·92 bushels, at 60 lb. per bushel, should be adopted in annually estimating the requirement in the near future, or whether, provisionally, the round number of 6 bushels per head at 60 lb. per bushel should be taken for some years, until experience shows how far that estimate is borne out by the subsequent records of the total amounts available and used.

It is in favour of adopting the higher figure that, after very full consideration of the great difficulty of forming anything like a trustworthy estimate of the amount consumed other than as human food, and also the fact that it bears, at any rate ordinarily, a very small proportion to that so consumed, we decided that there would be less error in fixing the estimate of requirement per head, so as to include the very small average consumption in other ways, than in attempting to estimate the consumption by stock, &c., separately. On this point it may be observed that the consumption in manufactures of any kind is very small: and that, generally, it is only the offal wheat that is given to stock, and this is excluded in our estimate of yield per acre, and therefore in the reckoning of the total wheat available. It is true that when the price is very low, not only will more offal be dressed out, and the sample so improved for sale, but more or less saleable wheat will also be consumed by stock; but there is no reason to suppose that this has taken place to such an extent as to materially affect our estimates. Thus, if for the sake of illustration we were to assume that, with the present very low prices, one million quarters of saleable home or imported wheat were consumed by stock, this would represent, on our average area under the crop over the last eight years, more than 3 bushels per acre, and on our average population over the same period 0·21, or about one-fifth of a bushel per head. It will be admitted that in the past, at any rate, the quantity of saleable wheat so appropriated has been much less than this; but what it may be under conditions of excessive supply and very low price, such as prevail at the present time, it is difficult to predict.

Upon the whole it is concluded that it is safer to form an estimate of requirement per head in the near future, including

consumption or use in other ways, rather higher than the amount indicated to have been actually available and used in recent years, and we adopt, therefore, provisionally, an estimated requirement per head per annum of 6 bushels at 60 lb. per bushel.

Price per Quarter, and Aggregate Value, of the Total Wheat annually available; also the Aggregate Cost, and the Cost per Head, of the Annual Requirement.

Referring as usual to Appendix-Table II. (facing p. 58), for the details, the summary Table (XII.) on p. 46 shows the averages for each of the eight-yearly periods, and for the forty years. The results are, in all cases, calculated for harvest not civil years.

As to the average *Gazette* price of the home wheat per quarter, as given in the first column, we understand that it frequently refers to quarters by measure irrespectively of weight; but that when weight is known to enter into the transaction, it is calculated to apply to quarters of 480 lb. = 60 lb. per bushel. The values for the home-crop, given in the second column of the Table, are reckoned at the *Gazette* price, on quarters of 480 lb. throughout. It is probable that, taking the average of seasons, the weight of the portion returned in measure only, would average more than 60 lb. per bushel; and, so far as it is so, the aggregate values given will be somewhat too high. It must be admitted, however, that there is by no means the certainty that would be desirable as to the weight represented by the quarters to which the *Gazette* price applies.

As the imports include both wheat imported as wheat, and flour as such, the *Trade and Navigation Returns* give the declared value of the imported wheat, and of the imported flour, separately. It seems inappropriate, however, for our present purpose—that of comparing the aggregate value of the home and the imported wheat—to include the value of the manufactured article—flour, as such. For the purposes of the Table, therefore, we have first converted the flour into its equivalent of wheat, and then reckoned the value as such, at the same rate as given for the wheat imported as wheat. On former occasions, we have calculated the value of imported wheat at the *Gazette* price per quarter of the home wheat; but it is pretty certain that this gives the value of the imported sometimes too high and sometimes too low. Thus, Mr. Rew, in this Journal (Vol. I., 3rd Series, Part III., 1890) showed that, according to the Official Returns, in 1889 imported wheat averaged 2*s.* 10*d.* per quarter more than the *Gazette* price of home wheat; and in the calculations for the present paper we have found that, although the difference varies greatly from year

to year, the declared values of imported wheat in some years show a rate per quarter of several shillings more, and in others of several shillings less, than the *Gazette* price. Accordingly, we now adopt the rate per quarter of the declared value instead of the *Gazette* price as formerly, for imported wheat—excepting for the first four years, for which the data are not available, and hence for them the *Gazette* price is still taken. There can be little doubt that the figures now given are nearer the truth than if the *Gazette* price were adopted throughout. At the same time, it is not clear how far the values given for the imported wheat, either accord with the values as sold in our markets, or compare strictly with the local market values of the home-crop.

TABLE XII.

—	Average *Gazette* price of home wheat per quarter	Price per quarter of imported wheat according to Trade and Navigation Returns	Value of wheat available for consumption. Home at average *Gazette* price; imports, wheat, and flour as wheat, at rates for wheat, according to the declared value in the Trade and Navigation Returns			Value of wheat estimated to be required	
			From home produce	From imports	Total	Total	Per head
	s. *d.*	*s.* *d.*	£	£	£	£	*s.* *d.*
Averages for :—							
8 years 1852-3 to 1859-60	57 8	(57 8)	38,420,217	13,518,974	51,939,191	52,494,776	37 6
8 „ 1860-1 „ 1867-8	52 2	49 6	31,355,606	20,956,252	52,311,858	53,152,383	35 8
8 „ 1868-9 „ 1875-6	52 0	49 0	30,535,899	26,742,885	57,278,784	57,609,561	36 1
8 „ 1876-7 „ 1883-4	45 7	46 2	20,280,559	37,413,986	57,694,545	57,943,572	33 6
8 „ 1884-5 „ 1891-2	32 5	33 9	14,108,380	31,601,890	45,710,270	45,660,252	24 8
40 „ 1852-3 „ 1891-2	47 11	(47 3)	26,940,132	26,046,797	52,986,929	53,372,109	33 6

Referring first to the particulars relating to the home-crop, it is seen that the *Gazette* price of wheat per quarter averaged 57*s.* 8*d.* over the first eight years, declined 5*s.* 6*d.* per quarter over the second period, and only 2*d.* more over the third, by 6*s.* 5*d.* over the fourth, and by 13*s.* 2*d.* over the fifth; the average price for those last eight years being only 32*s.* 5*d.* per quarter, or 25*s.* 3*d.* less than over the first eight years, and less than three-fifths, indeed not much more than half as much as over those first eight years. In reference to the higher range of prices during the first three periods, it is to be borne in mind that, during the first period there was the Crimean war, during the second the American Civil War, and during the third the Franco-German war.

The most marked decline in price was during the last

eight years, but the fourth period of eight, 1876–7 to 1883–4, shows the commencement of the rapid fall; and it was during that period, including the disastrous harvest of 1879, and, in all, six years of less, and sometimes much less, than average yield, that the aggregate home-crop declined so rapidly; whilst it was coincidently with this that the imports began so enormously to increase, and prices so seriously to go down. Then as to the last eight years, 1884–5 to 1891–2, notwithstanding a higher average yield per acre than over either of the other eight-yearly periods, the aggregate home-crop came down to even less than over the previous eight years; the imports were larger than ever, and the price, accordingly, was much lower than ever. In neither of those last eight years, however, was the average *Gazette* price for the year so low as 30*s.* per quarter; but it was frequently below it in individual months of the period. Thus, in the first of the eight years, 1884–5, it ranged from 31*s.* 2*d.* in December to 36*s.* 8*d.* in May; in the second year from 29*s.* 6*d.* in February to 32*s.* 6*d.* in August; in the third, from 30*s.* in October to 35*s.* 8*d.* in January; in the fourth, from 29*s.* 1*d.* in September to 35*s.* in August; in the fifth, from 35*s.* 10*d.* in September to 28*s.* 6*d.* in June; in the sixth, from 29*s.* 8*d.* in October to 36*s.* 2*d.* in August; in the seventh, from 31*s.* in October to 40*s.* 4½*d.* in May; and in the last year, 1891–2, from 38*s.* 5*d.* in September to 29*s.* 3*d.* in July; whilst in no week since the end of the last harvest-year—August 31, 1892—has the price been so high as 30*s.*, and in the week ending March 18, 1893, it reached its lowest point, namely—24*s.* 9*d.*!

The third column shows the average aggregate value per annum, at the *Gazette* price per quarter, of the saleable wheat crop of the United Kingdom, over each eight-yearly period, and over the forty years; and it is this that illustrates the most strikingly the reduction in value to the farmer of the crop which formerly constituted a very important, if not the most important, item of his marketable produce. The average annual value of the crop was nearly 38,500,000*l.* over the first eight years, more than 31,000,000*l.* over the second, and more than 30,500,000*l.* over the third eight years; it then comes down to little more than 20,000,000*l.* over the fourth eight, and to little more than 14,000,000*l.* over the last eight years; whilst in 1887–8 it was less than 12,500,000*l.* In other words, the aggregate value of the saleable wheat crop of the country came down from about 38,500,000*l.*, over the first eight years, to little more than 14,000,000*l.* over the last eight, or to not much more than one-third. In fact, the value of the home wheat crop averaged more than 24,000,000*l.* less per annum over the last eight

than over the first eight of the forty years! The result was to a great extent due to reduction in area, itself the result of reduction in price, which also greatly reduced the value of the much smaller crops grown. It has, indeed, been reduction in price, to which both reduction in area, and reduction in aggregate value, are to be attributed.

The causes of the disastrous results to our own wheat growers are plainly seen in the records given in the fourth column of Table XII., which shows the value of the imports, calculated according to the declared values given in the Trade and Navigation Returns, as above referred to.

But, before comparing the aggregate values of the home-crops and the imports, it will be well to direct attention to the difference between the *Gazette* price per quarter of the home, and the price of the imported wheat obtained as above explained. Reference to the details given in Appendix-Table II. (facing p. 58), will show that the so reckoned prices of the home and the imported wheat varied considerably in the individual years; that during the earlier half of the period the price of the imported was generally lower, but during the later years higher than that of the home wheat. In some cases the difference amounts to as much as 4*s.*, 5*s.*, and in one to 6*s.* 9*d.* per quarter; but it is less in the later than in the earlier years. Much will probably depend on the comparative condition of the home and foreign wheats in the individual years; and it is also probable that the condition of the imported wheat has been relatively better in the later years. But it is remarkable, as will be seen by reference to the figures in the bottom line of Table XII., that over the thirty-six years for which the comparison can be made, there is an average difference of only 8*d.* per quarter; and that is in favour of the home wheat. Lastly, in reference to these records of price per quarter, as already stated, there is uncertainty as to the weight per quarter to which the *Gazette* price of the home wheat applies. In the case of the imported wheat, however, the declared values are given for quantities stated in cwt., and we have calculated them for quarters, of 480 lb. =60 lb. per bushel, as adopted throughout in Appendix-Table II., and in the summary Tables founded upon it. The two sets of prices are, therefore, so far, not strictly comparable; nor, as already said, is it clear that the declared values of the imported wheat accord with the prices as sold in our markets.

Referring to the results given in the fourth column of Table XII., it is seen that the average annual value of imported wheat, and flour reckoned as wheat, was, over the first eight years, little over 13,500,000*l.*, over the second eight about 21,000,000*l.*,

or more than one-and-a-half time as much, over the third eight years nearly 26,750,000*l.*, over the fourth about 37,400,000*l.*, and over the fifth, with larger quantities than ever, but with very low price, 31,600,000*l.* To put it in another way, the value of the imports was not much more than one-third that of the home-crop over the first eight years, about two-thirds as much over the second eight, about nine-tenths as much over the third eight, nearly twice as much over the fourth eight, and considerably more than twice as much over the last eight years.

Turning now to the fifth or "total" column, it is seen that, notwithstanding the great decline in the aggregate value of the home-crop from period to period, there is, with a greater proportional increase in that of the imports, a notable increase in the annual aggregate value of the total wheat available over the third and fourth compared with the first and second periods; but, over the last eight years, in spite of the increased quantities, the annual aggregate value was, with the extremely low price per quarter, scarcely four-fifths as much as over the two preceding periods. It may here be observed that, whilst over the last eight years the home-crop has, both in quantity and in value, supplied less than one-third the requirement of the country, it is to be feared that the crop of the last harvest, 1892, will yield less than one-fourth of the total requirement. Such are the facts and their bearing from the point of view of their influence on our home agriculture. No wonder that under such conditions a conference to consider the depression in agriculture should have been convened.

The concluding columns of the Table show the estimated average annual value of the wheat required for consumption, both aggregate and reckoned per head of the population, over each of the five periods and over the forty years. Of course, with an equal value per quarter, the aggregate value must increase from year to year with the increase of the population. But it is seen that there is considerable increase from the first to the fourth period, notwithstanding the reduction in price per quarter. Over the fifth period, however, with a still greater reduction in price per quarter, the aggregate value of the wheat required is only about four-fifths as much as over the third and fourth periods; and, notwithstanding a larger population by about one-third, nearly 7,000,000*l.* less than over the first eight years. In other words, the aggregate cost of the wheat required by an average population of about 37,000,000 over the last eight years was about 7,000,000*l.* less than that of the amount required at even a slightly lower rate per head, by an average population of about 28,000,000 over the first eight years.

It will be seen that the aggregate value of the wheat annually required does not quite agree with that of the wheat annually available, and it is generally somewhat higher. The two values are, however, reckoned at the same rates per quarter each year; but as the quantity "available" within the harvest-year sometimes includes a considerable excess over the amount required for consumption within the year, there being frequently a quantity brought forward, or carried over to the next or even subsequent years, it may be with a price differing from that of the year in which it comes in under the head of "available;" and hence the discrepancy between the two reckonings. The results are, however, as nearly true as the facts admit of; and they are sufficiently correct for the purposes of our illustration.

Referring now to the last column in the Table (XII.), it is seen that the cost of wheat per head to the consumer averaged, with considerable variation between individual years, the highest over the first eight years, and was not much lower over the next two eight-yearly periods; there being at the same time a less reduction in price per quarter than afterwards. Thus, the average cost per head was 37*s.* 6*d.* over the first eight years, 35*s.* 8*d.* over the second eight, and 36*s.* 1*d.* over the third eight. But, with the greater reduction in price per quarter over the fourth eight years, the cost per head was reduced to 33*s.* 6*d.*; and with the still greater reduction over the last eight years, to 24*s.* 8*d.* per head. That is to say, with enormous imports, and extremely low price per quarter, the cost of wheat per head of the population over the last eight years was less than two-thirds as much as over the first eight, and little more than two-thirds as much as over the first twenty-four years of the forty. Lastly, it may be stated that, of the total cost per head, imported wheat supplied about 26 per cent. over the first eight years, about 40 per cent. over the second eight, nearly 47 per cent. over the third eight, about 65 per cent. over the fourth eight, and nearly 70 per cent. over the last eight years. However disastrous, therefore, the large imports of wheat, and the greatly reduced price per quarter, may have been to the home producer, the consumer has, so far as the cost of this staple article of his food is concerned, reaped immense advantages.

General Considerations and Conclusions.

Among our arable land crops, it is not only the production of wheat that has declined. The decline in the home crop of wheat may be said to have commenced about twenty years ago, but to have been the most marked during the last thirteen or fourteen

years. The area under barley has declined very considerably since the repeal of the malt-tax in 1880, and the imports have increased in a greater proportion. Our area under oats has fluctuated, but not materially diminished, during the last twenty years, though it has shown a tendency to do so during the last four or five years. The imports have, however, very considerably increased. The agricultural area under potatoes in the United Kingdom has not varied very much during the last twenty years. It was, however, higher over the first five years than it has been during any equal period since; and there has been a decided tendency to reduction during the last few years. Notwithstanding this, the imports have averaged considerably less than half as much over the last ten as over the first ten of the last twenty years. It is probable that the reduction of the available supply of potatoes per head of the population which these facts taken alone would indicate has been to some extent compensated by an increased growth of the crop in market gardens, the area of which has, it is satisfactory to note, increased considerably in recent years. It is also probable, however, that there has in reality been some reduction in the actual consumption per head under the influence of the cheapening of bread-stuffs Of other crops, chiefly used as stock foods, and which are also products of home growth, our own area under beans and peas has in recent years declined, but the imports have been about one-eighth more over the last ten than over the preceding ten years. Then, of stock foods (of course also yielding manure) not grown at home, the annual imports of Indian corn have been about one-third more over the last fifteen than over the preceding five years; those of oil-cakes have increased by considerably more than one-half; those of cotton-seed by nearly one-third; and those of linseed by one-fourth more, over the last ten than over the preceding ten years.

The general result is, that our own arable area has gone down from an average of 23,808,294 acres over the first five of the last twenty-five years to 1892 inclusive, to 20,856,075 over the last five; in other words it has declined by 2,952,219 acres. Against these results, it is satisfactory that the area returned as under permanent grass has, over the same periods, increased from 22,485,020 acres to 27,146,147, or by 4,661,127 acres. With this increase in feeding area, and increase also of imported food-stuffs, there has, comparing the last ten years to 1892 inclusive with the preceding ten, been an increase in our average annual number of cattle from 9,965,546 to 10,709,656, or by 744,110; a decrease in that of sheep from 31,718,768 to 30,343,502, or by 1,375,266, and an increase in that of pigs

from 3,532,015 to 3,841,959, or by 309,944. Yet, over the same periods, there has been an average annual increase in the imports of cattle from 268,514 to 447,347, or by 178,833, but a decrease in that of sheep from 934,874, to 723,859 or by 211,015, and a decrease in that of pigs from 53,155 to 18,338, or by 34,817. There has, on the other hand, been an average annual import of 7,281,330 cwt. of dead meat, fresh and salted, over the last fifteen years, against only 3,915,516 cwt. over the preceding five years, or nearly twice as much over the later years.

Thus, although our own feeding area, and the imports of stock-foods, have greatly increased during recent years, with this our live stock has also increased, so also have the imports of live animals and of dead meat. It is obvious that the staple products of the feeder, like the crops of our arable land, have been insufficient to meet the requirements of a rapidly increasing population.

In connection with this question of our home production on the one hand, and imports on the other, it will be of interest to consider our position in regard to some of the smaller articles of agricultural production. Those of most importance to the farmer are—poultry and eggs, and the dairy products, milk, butter, and cheese. In our paper on *Allotments and Small Holdings*, in a recent number of this Journal (Vol. III., 3rd Series, Part III., p. 439), we called attention to the fact that, in 1890, the values of our imports were—of butter 10,598,848*l.*, of cheese 4,975,134*l.*, of eggs, 3,428,806*l.*, and of poultry and game, 497,857*l.*; or in all for these articles 19,500,645*l.* In 1892, however, the values of the imports were—of butter, 11,965,284*l.*, of cheese 5,417,777*l.*, of eggs 3,793,018*l.*, and of poultry and game 583,430*l.*; or in all 21,759,509*l.* Thus the increase in the value of the imports of these articles in 1892 compared with 1890 was—for butter 1,366,436*l.*, for cheese 442,543*l.*, for eggs 364,216*l.*, and for poultry and game 85,572*l.*; or in all 2,258,767*l.*

In reference to these amounts it may be stated that the value of the poultry and game imported was nearly three times as much over the last five years as over the first five of the last twenty years to 1892 inclusive, and that the number of eggs imported was nearly double over the last compared with the first five years of the twenty. More attention might perhaps with advantage be paid to the home production of poultry and eggs; but, with our climate, any really material increase in such production could only be attained by outlay for protection from the weather, and perhaps for artificial heat, during the colder months of the year; whilst the expenditure for food would be the greater the less the

birds had to rely on the waste corn and other matters they could pick up about the farm, as they largely do at present.

As to butter, unfortunately until the last few years "butterine" or "margarine" was included with butter in the returns, which show, of the two together, a very great increase. Probably in the earlier years of the Returns, the imports were chiefly butter; but during the last seven years to 1892 inclusive, when margarine has been given separately, it contributed from one-third to one-half of the total quantity of the imports, which were more than twice as great over the last five as over the first five of the last twenty years. Certainly there has been great room for improvement, and, indeed, there still is, in the quality of much of our home-made butter. But, thanks to the good work done in technical teaching on butter-making during the last few years, some improvement has already been attained; and there is every reason to hope that it will be more general in the near future. As to quantity, the home product has probably increased to some extent in recent years; but when it is considered that to produce, in addition to the present home yield, the amount annually imported, would require a very large area of grass land, besides a good deal of arable land produce, and of imported food-stuffs as well, the hopelessness of meeting the whole requirement of our present, to say nothing of an increased, population is obvious.

Then as to cheese, our imports have gradually increased during the last twenty years; and they have been about one-third more over the last five than they were over the first five of the twenty years. As in the case of butter, so in that of cheese, improvement in the making is taking place, under the influence of more widely disseminated technical teaching. But to increase the quantity so as to meet the requirement for consumption without imports would again involve the devotion of a very large acreage of grass—the more the less suitable the land for the purpose; besides, as in the case of butter, the use of a considerable quantity of arable land produce and of imported food. In fact, to produce the increased amounts of butter and cheese supposed, would require several million acres of grass-land, necessarily displacing some other produce, involving increased importation of something else to compensate the loss; and it would also require increased importation of food-stuffs for the cows.

As to fruit and vegetables, the annual value of the imports of which is considerable, their increased production at home is more dependent on local circumstances of soil and climate than is that of some of the more purely agricultural and more important products. It is satisfactory to note, however, that, according to

the Returns, the area under market gardening in Great Britain has been about twice as great during the last five as during the first five of the last twenty years; and the rate of increase has been the greater during the last few years. Still, our imports of fruit and vegetables have also increased; and there is little hope that we can effectively compete with the countries from which we derive large supplies of certain fruits, and of early vegetables, which command the highest prices.

Although, therefore, there is evidence of some increase in the home production of the various smaller articles, and further extension seems both probable and promising, yet there can be no hope that the home production of these articles can be so raised as to meet the requirement of our present, to say nothing of an increasing, population.

But, in an article in the *Nineteenth Century* of December 1892, Mr. Jesse Collings, M.P., calls attention to the fact that, leaving corn and cattle out of the question, we in 1891 imported other articles of agricultural produce to the value of more than 38,000,000*l.* The articles he enumerates are—cheese, butter, margarine, lard, poultry, game and rabbits, bacon and hams, pork—fresh and salted, potatoes, eggs, and apples; and he asks—"Why cannot the farming industry supply our home market—the best of all markets—with sufficient quantities of the articles named?" He says the question arises: "Why should an industry be subject to continual depression which has such a vast amount of trade offered at its very doors? What would be said of a body of manufacturers who had available men and material, but who, through failing to adapt their productions to the demand, allowed half the orders offered them to go to foreign countries, and who nevertheless complained of depression in trade?" He adds—"The matter is one of national importance, as affecting the trade of the country, and it is time for the shopkeeper, the manufacturer, and the commercial classes generally to take it up." And again he says—"If a few thousand pounds' worth of steam-engines or iron girders are imported from Belgium, the Chambers of Commerce and the commercial press are alive to the dangers therefrom to British manufacturers, but no anxiety at all is shown at the steady increase in our imports, say, of cheese, which in 1891 amounted in value to nearly 5,000,000*l.* sterling. Surely this country is as fitted to produce cheese as it is to manufacture steam-engines and girders!"

Now it so happens that in the very same number of the *Trade and Navigation Returns*, which gives the list of articles of agricultural produce imported in 1891, to the value of more than 38,000,000*l.*, we find that—under the head of "Manufactured

Articles"—clocks, cotton manufactures, glass, hats and bonnets of straw, iron girders, beams, pillars, and other articles, leather, boots, shoes, and gloves, paper, silk, straw-plait, watches, woollen manufactures, silk manufactures, and others not enumerated, were in the same year (1891) imported to the value of more than 65,000,000*l.*! No doubt the home producers of these various articles would be able satisfactorily to explain why the large amounts of them imported are not produced at home instead, when such numbers of our population are unemployed; and doubtless the various reasons could be summed up in the few words—it would not pay! Agriculturists, we suppose, would not presume to pass a judgment on the validity of the reasons given by the experts in the different branches of manufacture. But agriculturists are treated in a very different manner by those who apparently know as little about the necessary conditions of profitable agriculture, as agriculturists may be supposed to do of the various manufactures of which we import 65,000,000*l.* worth a year!

The truth is that, for the essential purpose of providing cheap food for the people, and for the urban manufacturing populations especially, free trade in agricultural produce has been established, and imports have, accordingly, immensely increased. An inevitable result of this has been a great reduction in price, the cost for bread-stuffs alone having been, as we have shown in this paper, less than two-thirds as much per head of the population during the later as during the earlier years of the period of our inquiry. A necessary consequence has been to reduce the area under grain crops, and with this the area under the plough, in our own country, and hence to reduce the amount of labour required to a given area, and so naturally to reduce the rural population. A further consequence has been great reduction in rents, and serious loss of tenants' capital. But the urban and manufacturing populations resent the idea that they should bear any share of the burden resulting from the competition with foreign producers, and the great reduction in price chiefly in their interest, necessitating as it does a less requirement for rural labour, which, together with a rapidly increasing population, leads many to go into the towns. It so happens, too, that the most practicable suggestions for change in our agricultural system would only tend to increase the particular evil complained of, by still further reducing our arable and increasing our grass land area; whilst some of the schemes proposed are of very limited applicability, and others would pretty certainly be unprofitable, if not indeed attended with considerable loss.

We have indicated above in which direction there seems the

best prospect of improvement or extension in the production of some of the smaller articles of which we import so much; and we should desire to give every encouragement to well-directed effort. At the same time, we are firmly of opinion that it is out of the question to look for anything like such a result as a greatly increased production of some of the articles enumerated. Nor do we believe that an extensive application of the *Small Holdings Act* would bring about the changes anticipated to anything like the extent that seems to be assumed. County Councils, to whose judgment and action in the matter Mr. Collings looks forward so sanguinely, will, after all, have to face the question—will it pay?

But to return to the question of wheat production, which is our special subject on the present occasion: In our paper on *Allotments and Small Holdings*, above referred to, we showed that, with the rapid increase of population which had taken place, it would have been impossible for our own country to have produced all the wheat required for consumption; and that, should the increase continue, it will be in a greater degree impossible in the future. It was pointed out, that the area under wheat in the United Kingdom had during the last eight years averaged rather less than one-eighth of the total arable area; and that to produce all the wheat required for consumption, more than one-third of our existing arable area would be required; or that, if the area devoted to other rotation crops were to continue to bear about the same relation to that under wheat as in recent years, the total arable area would have to be increased nearly three-fold, making in all much more than our present total arable and grass areas put together; or that, if wheat were to be grown on a larger proportion of the existing arable area, it could only be by the exclusion of the growth of other grain crops and stock-foods, which would then, in their turn, have to be imported in larger quantities; or, our stock must be reduced, and our imports of live animals, dead meat, and dairy produce, be very much increased.

Doubtless, if the price of wheat were materially to recover, the area under the crop would again increase; but it is obvious that with an annually increasing population, and demand for sustenance, it is hopeless to suppose that we can supply from home produce even so large a proportion of the total amount required as during the earlier periods to which our inquiry relates. Indeed, it is evident that, even if our wheat area were to regain its former proportions, it could, with the rapidly increasing demands for other products, only be by the

displacement of some of them, which would then have to be imported instead of grown at home.

In conclusion, it must be admitted that, unless low prices should check the production of grain for export in other countries, or from any other cause prices should rise, there is little likelihood that our own farmers will have much inducement to increase their area under grain crops. Under such circumstances, a larger proportion of the remaining arable area will be devoted to the growth of stock-foods, and, with the increased and increasing area under grass, the production of meat and dairy produce may acquire increased importance in our own agriculture; that is, provided the farmer be protected from imported cattle disease, and from the importation of adulterated dairy products. But it is to be borne in mind, that material increase in the production of meat, milk, butter, and cheese, cannot be attained without the aid of imports of stock-foods, providing both food and manure, and of some direct manures also; whilst, with our increased and increasing population, and limited agricultural area, it cannot be expected that the demands for home consumption can be met without large imports of both grain and the products of feeding. Lastly, with the decrease of arable area, and the increase of permanent grass and of feeding, the number of the population engaged in rural pursuits must necessarily diminish.

JOHN BENNET LAWES.
JOSEPH HENRY GILBERT.

APPENDIX-TABLES.

I. (p. 58).—Home Produce, Imports, and Consumption of Wheat, in the United Kingdom, 40 Harvest-Years, 1852–3 to 1891–2, inclusive.

II. (facing p. 58).—Home Produce, Imports, Consumption, and Price of Wheat, in the United Kingdom, 40 Harvest-Years, 1852–3 to 1891–2, inclusive.

APPENDIX-TABLE I.—*Home Produce, Imports, and Consumption of Wheat, i the United Kingdom,*[1] 40 *Harvest-Years,* 1852–8 *to* 1891–2, *inclusive.*

[N.B.—Home produce at 61 lb., imports at 60¾ lb. per bushel; 80·77 flour reckoned = 100 wheat. Population as formerly given.

Harvest-years September 1 to August 31	Estimated home produce (bushels of 61 lb.)			Available for consumption			Population (middle of harvest-years)	Available for consumption per head within each year		
	Area under the crop[1]	Average yield per acre	Total home produce	Home produce less 2¼ (or 2)[2] bushels per acre for seed	Imports less exports	Total		From home produce	From imports	Total
	Acres	Bush.	Quarters	Quarters	Quarters	Quarters		Bush.	Bush.	Bush.
1852–3	4,058,731	22⅞	11,574,982	10,433,464	5,807,292	16,240,756	27,511,144	3·03	1·69	4·72
1853–4	4,013,963	20⅞	10,466,473	9,337,546	5,851,960	15,189,506	27,619,999	2·70	1·70	4·40
1854–5	4,036,969	34½	17,563,140	16,427,742	2,647,314	19,075,056	27,767,388	4·73	0·76	5·49
1855–6	4,076,447	27⅜	13,922,801	12,776,300	3,689,009	16,465,309	27,947,933	3·65	1·06	4·71
1856–7	4,213,651	27	14,192,543	13,007,453	4,014,940	17,022,393	28,129,198	3·70	1·14	4·84
1857–8	4,185,974	33½	17,321,221	16,143,915	5,766,643	21,910,558	28,322,607	4·56	1·63	6·19
1858–9	4,131,822	31½	16,309,949	15,147,874	4,971,278	20,119,152	28,523,406	4·25	1·39	5·64
1859–60	4,019,725	26⅛	13,135,124	12,004,575	4,484,695	16,489,270	28,715,682	3·34	1·25	4·59
1860–1	3,992,657	22½	11,078,948	9,956,012	10,112,748	20,068,760	28,909,045	2·75	2·80	5·55
1861–2	3,898,177	25½	12,271,546	11,175,183	8,882,890	20,058,073	29,128,110	3·06	2·44	5·50
1862–3	3,823,947	29½	13,957,554	12,882,069	9,102,914	21,984,983	29,331,695	3·51	2·48	5·99
1863–4	3,698,629	38⅜	17,922,048	16,881,807	6,906,087	23,787,894	29,509,228	4·57	1·87	6·44
1864–5	3,685,493	35½	16,216,328	15,179,783	5,454,547	20,634,330	29,700,831	4·09	1·47	5·56
1865–6	3,646,691	30⅝	13,975,936	12,950,305	7,273,595	20,223,900	29,886,735	3·47	1·94	5·41
1866–7	3,649,584	25½	11,485,091	10,458,645	7,541,655	18,000,300	30,087,001	2·78	2·00	4·78
1867–8	3,628,910	21	9,566,522	8,545,890	9,104,664	17,650,554	30,299,054	2·26	2·40	4·66
1868–9	3,937,275	34	16,733,419	15,626,060	8,115,943	23,742,003	30,525,967	4·09	2·13	6·22
1869–70	3,976,147	27	13,419,496	12,301,205	9,906,858	22,208,063	30,760,150	3·20	2·58	5·78
1870–1	3,761,457	30	14,105,464	13,047,554	8,089,016	21,127,570	31,299,067	3·33	2·07	5·40
1871–2	3,818,848	24	11,456,544	10,382,493	9,424,253	19,806,746	31,749,121	2·62	2·37	4·99
1872–3	3,827,146	24	11,481,438	10,405,053	12,424,700	22,829,753	32,040,636	2·60	3·10	5·70
1873–4	3,658,815	22½	10,290,417	9,261,375	11,284,136	20,545,511	32,318,503	2·29	2·80	5·09
1874–5	3,821,655	29½	13,972,926	12,898,085	11,705,254	24,603,339	32,628,940	3·16	2·87	6·03
1875–6	3,503,709	22½	10,018,418	9,033,000	13,860,079	22,893,079	32,974,761	2·19	3·36	5·55
1876–7	3,114,555	25	9,732,984	8,857,015	12,107,293	20,964,308	33,327,426	[illegible]	90	5·03
1877–8	3,311,859	26½	10,970,533	10,039,073	14,408,628	24,447,701	33,736,117	2·[illegible]		5·80
1878–9	3,372,590	30	12,647,213	11,698,672	14,145,647	25,844,319	34,064,731	2·75	4·32	6·07
1879–80	3,047,752	15½	5,905,020	5,047,840	16,409,933	21,457,773	34,388,733	1·17	3·82	4·99
1880–1	3,057,784	24½	9,364,464	8,504,462	16,079,311	24,583,773	34,788,371	1·95	4·70	6·65
1881–2	2,960,066	24	8,880,198	8,047,679	17,077,974	25,125,653	35,163,544	1·83	3·89	5·72
1882–3	3,157,924	25⅝	10,115,225	9,227,059	19,947,156	29,174,215	35,514,293	2·08	4·49	6·57
1883–4	2,707,949	28	9,477,822	8,616,211	15,780,731	24,396,942	35,845,007	1·92	3·52	5·44
1884–5	2,744,928	29⅜	10,079,032	9,307,021	17,971,566	27,278,587	36,200,698	2·06	3·97	6·03
1885–6	2,549,335	30½	9,639,673	8,922,673	15,153,636	24,076,309	36,579,984	1·95	3·32	5·27
1886–7	2,355,451	29½	8,612,118	7,949,647	17,346,795	25,296,442	36,963,515	1·72	3·75	5·47
1887–8	2,384,505	28⅜	8,457,541	7,861,415	16,689,389	24,550,804	37,332,904	1·68	3·58	5·26
1888–9	2,663,250	26⅞	8,946,855	8,281,042	18,007,974	26,289,016	37,690,453	1·76	3·82	5·58
1889–90	2,539,099	29½	9,362,928	8,728,153	18,074,666	26,802,819	38,087,845	1·83	3·80	5·62
1890–1	2,478,677	31¼	9,759,791	9,140,122	17,973,042	27,113,164	(37,693,356)	1·94	3·81	5·75
1891–2	2,388,147	29½	8,806,292	8,209,255	21,889,695	30,098,950	38,007,239	1·73	4·61	6·34

AVERAGES.[3]

Periods of 8 years										
1852–3 to '59–60	4,092,160	26	14,310,779	13,159,859	4,654,141	17,814,000	28,067,170	2·74	1·23	5·[illegible]
1860–1 to '67–8	3,753,011	28⅜	13,309,247	12,253,712	8,047,387	20,301,099	29,606,462	3·31	2·18	5·[illegible]
1868–9 to '75–6	3,788,132	26⅝	12,684,765	11,619,353	10,600,155	22,219,508	31,787,143	2·93	2·66	5·[illegible]
1876–7 to '83–4	3,091,310	24¾	9,636,682	8,754,751	15,744,584	24,499,335	34,603,528	2·03	3·63	5·[illegible]
1884–5 to '91–2	2,512,924	29⅜	9,206,029	8,549,916	17,888,345	26,438,261	37,319,499	1·83	3·63	5·[illegible]
40 yrs. 1852–3 to '91–2	3,447,507	27½	11,829,900	10,867,518	11,886,923	22,254,441	32,276,760	2·77	2·73	5·[illegible]

[1] Exclusive of the islands in the British seas.
[2] From 1852–3 to 1886–7, 2½ bushels; 1887–8 and since, 2 bushels.
[3] The "Averages" are, in each case, the mere means of the figures in the columns for the respective period

Kingdom,[1] 40 *Harv*

heat. Population accor

per head	Average *Gazette* price of home wheat per quarter
Total	
Bushels	s. d.
4·85	44 7
4·52	72 11
5·60	70 1
4·84	73 11
4·96	60 1
6·32	47 8
5·75	43 8
4·68	48 3
5·70	55 3
5·64	58 2
6·14	47 8
6·58	41 0
5·66	40 1
5·51	46 6
4·84	60 4
4·70	68 4
6·29	50 0
5·84	46 2
5·48	54 2
5·09	56 7
5·83	57 4
5·20	61 3
6·15	44 7
5·66	45 11

ROTATION OF CROPS.

BY

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Introduction and Historical Sketch.

It has frequently been explained that the general scope and plan of the Rothamsted field experiments have included the growth of some of the most important crops of rotation, each separately, year after year, for many years in succession on the same land, without manure, with farmyard manure, and with a great variety of chemical manures—the same description of

manure being, as a rule, applied year after year on the same plot. But, besides such experiments, what may in a sense be called complementary series have also been made—on the growth of crops in an actual course of rotation, without and with different manures. Lastly, others have been conducted on the mixed herbage of permanent grass-land, both without and with various manures.

It is obvious that the results of the field experiments with individual crops must of themselves throw much light on the characteristic requirements of the particular crop under investigation; whilst those on the growth of crops in an actual course of rotation will serve to confirm and control those obtained with the individual crops; and they will, in their turn, receive elucidation from the results with the individual crops. Then, again, the results of experiments on the application of different manures to the mixed herbage of permanent grass-land, which includes, among others, members of the botanical families that contribute some of the most important of our rotation crops, may, independently of their value in reference to the special objects for which they were undertaken, be expected to afford interesting collateral evidence in regard to the requirements of individual plants when thus grown in association, instead of separately year after year, or in rotation, as in the other series of experiments. Obviously, too, the chemical statistics of the crops so variously grown, and of the soils of the plots upon which they have been grown, must afford very important data for further study and elucidation.

The individual crops which have been grown separately year after year on the same land include—wheat, barley, and oats, as members of the Order Gramineæ; beans, clover, and other plants, of the Order Leguminosæ; turnips of the Cruciferæ; sugar-beet and mangel-wurzel of the Chenopodiaceæ; and potatoes of the Solaneæ. Then, the experiments on rotation include those with members of three different Orders of plants —turnips of the Cruciferæ, barley and wheat of the Gramineæ, and clover and beans of the Leguminosæ. Lastly, there are the experiments on the mixed herbage of permanent grass-land, which, besides gramineous and leguminous plants, includes numerous species of other natural Orders.

The first experiments made were those with root-crops, which were commenced in June 1843, so that the present year (1894) is the fifty-second of their continuance. The second were those on wheat, commenced in the autumn of 1843, so that the crop just harvested is the fifty-first grown in succession on the same land. The experiments with beans were commenced in

1847; but, for reasons which have been explained in various papers, they have not been continued up to the present time. Those with clover were commenced in 1848, and have been succeeded on the same land by others with various leguminous plants, which are still continued. Then, of the other more important series, those on barley were commenced in 1852, and are still in progress, the crop of the present year being, therefore, the forty-third in succession. Experiments with oats were commenced in 1869, and continued for ten years; and others, on the growth of wheat alternated with fallow, but without manure, were commenced in 1851, and are still going on, 1894 being, therefore, the forty-fourth year. Of the other field experiments, those on the mixed herbage of permanent grass-land were commenced in 1856, so that this year completes the thirty-ninth of their continuance. Lastly, the experiments on an actual course of rotation were commenced in 1848, and are still continued, so that the present is their forty-seventh year.

In former papers in this Journal, and elsewhere, the influence of exhaustion, manures, and variations of season, on the amounts of produce, and on the composition, of certain individual and typical crops, when each is grown separately year after year on the same land, have been considered. In this way, there have been discussed the characteristic requirements and results of growth—of various cereal crops, of various root-crops, of potatoes, and lastly, of various leguminous crops. Results of the experiments on the mixed herbage of grass-land have also been given from time to time.

Our subject on the present occasion is the *Rotation of Crops*. The mere numerical results of the field experiments made at Rothamsted on rotation have been recorded in the annual "*Memoranda*"; but no systematic discussion, either of them or of the laboratory investigations undertaken in connection with them, has hitherto been published; and although the present communication embodies a good deal of detail, and a somewhat comprehensive consideration of it, there still remains much which could not be included within the limits of this paper.

The practice of Rotation is admitted to be the foundation of the improvements in our own agriculture which have taken place during this and a considerable part of the last century. It is of great importance, therefore, carefully to consider, both in what the practice itself consists, and how its benefits are to be explained.

If the rotation of crops as followed in our own country, indeed over large portions of Europe, were to be defined in the fewest possible words, it might be said that it consists in the alternation of root-crops, and of leguminous crops, with cereals. In the

United States, however, it is a gramineous crop—maize—which largely takes the place of root-crops in Europe.

The cereals constituting such a very important element of human food, it was natural that they should be grown almost continuously so long as the land would yield remunerative crops. Hence, the history of agriculture, not only in our own country, but in others where these crops were of high relative value, shows that it very generally came to be the custom to grow them for a number of years in succession, and then to have recourse to bare fallow; or, in some cases, to abandon the land to the growth of rough and weedy herbage, affording scanty food for domestic animals.

The improvement upon these practices, attainable by alternating other crops with the cereals, was very much earlier recognised in the case of the leguminous than of the root-crops, the introduction of which is of comparatively recent date.

It was, in fact, distinctly recognised by the Romans more than two thousand years ago, not only that certain leguminous crops were valuable as food for animals, but that their growth enriched the soil for succeeding crops—in fact, that they were of value as restorative crops grown in alternation with the cereals. There is, however, very scanty indication that root-crops were an element in their alternate cropping.

As in the agriculture of the ancients, so in that of more modern times, especially in our own country, various leguminous crops were grown in alternation with cereals long before roots were so interpolated.

It was, indeed, not until about, or after, 1730 that Lord Townshend, who, as Secretary to George I., had been in Hanover, and there seen turnips growing as a field crop, on his return introduced them on his own estate in Norfolk, and there founded the celebrated Norfolk four-course rotation of turnips, barley, clover, and wheat. His own land was previously to a great extent a marshy or sandy waste, and its value was increased enormously under the new system. It was, however, not until towards the end of the century that it became generally adopted even throughout his own county. In this extension Mr. Coke, of Holkham (afterwards Earl of Leicester), was largely instrumental, and the practice seems to have next extended into Lincolnshire.

It was thus that *The Four-course Rotation*, or, in other words, the alternation of root-crops and of leguminous crops with cereals, became established. Such alternation is, in fact, the basis of all the various rotations which are adopted in

different parts of our own country, and also to a great extent which are followed in many other countries.

It is worthy of remark that, although we owe the introduction of the essential elements of our rotations to the example of our Continental neighbours, we, with one or two immaterial exceptions, obtain more per acre of all the staple saleable products of rotation, grain and meat, under our landlord, tenant, and labourer system, than any other country in Europe, or than in America, under whatever advantages of climate, or under whatever system of holding, or of size of holdings. Thus, there is not a single country in Europe that reaches our average produce per acre of wheat; only Belgium and Holland approach, but they do not equal, us in the produce of barley; only Belgium, Holland, and Norway exceed us in acreage yield of oats; and no country approaches us in acreage produce of potatoes. Again, whilst several countries exceed us in number of cows to a given area, and some in the number of pigs, not one equals us in weight per acre of other cattle than cows; and not one nearly approaches us in the weight of sheep to a given area. Nor, notwithstanding the great depression of our agriculture in recent years, the result of the low prices of produce, is there any probability that we shall soon lose our pre-eminence in production per acre.

There can be no doubt that the effect of the extension of the growth of green crops was—to a great extent to get rid of unprofitable fallows, greatly to increase the supply of stock food, especially for winter feeding; so to lead to a largely increased production of meat and milk, to a greatly increased supply of manure, and thus to enrich the land for the growth of grain, which, accordingly, yielded much larger crops.

We have now to endeavour to ascertain how the admittedly very beneficial effects of alternate, as distinguished from continuous, cropping are to be explained. It will be well first very briefly to refer to some of the chief theoretical explanations that have been put forward, and afterwards to discuss the results of various direct experimental investigations conducted at Rothamsted on the subject of rotation.

The first definite theory as to the benefits of the alternation of crops assumed that the excreted matters of one description of crop were injurious to plants of the same description, but that they were not so, and might even be beneficial, to other kinds of plants.

At first Liebig pronounced this theory of rotation to be the only one having any really scientific basis. Later he seems to

have modified his view considerably, and to have supposed that the explanation was—not that the excreted matters of one description of plant were injurious to another of the same description, but that, as the different plants had such very different mineral requirements, the alternation of one kind with another relieved the soil from exhaustion. In his latest work, however, after many years of controversy, he obviously more fully recognised that nitrogen probably played some important part in the matter.

More than fifty years ago Boussingault published the results of an investigation, extending over a period of ten years, to determine the chemical statistics of some of the rotations actually followed in his own locality, in Alsace: and he came to the conclusion that the difference in the amounts of nitrogen taken up by the different crops constituted a very important element in the explanation of the benefits of rotation.

We can only further briefly refer to the results and conclusions of the late Professor Daubeny, of Oxford, who commenced a series of experiments in the Botanic Garden there in 1834. One of the original objects he had in view was to test the truth of De Candolle's theory that the excretions of one description of plant were injurious to plants of the same description. He soon came to a negative conclusion on the subject; and recognised the validity of Boussingault's argument that the actual facts of vegetation in different parts of the world conclusively showed that the same description of plant may continue to grow healthily on the same land for long periods of time. On this point it is scarcely necessary to add that the experience at Rothamsted on the growth of various agricultural crops year after year on the same land for many years in succession is conclusive against the theory of injurious or poisonous excretions.

But, as already said, Dr. Daubeny continued his experiments for ten years; and although, in accordance with the prevailing ideas of the time, all his analytical results related to the mineral constituents of his soils and crops, his main conclusion was, that the benefits of rotation were probably as much connected with the available supply of the organic as of the inorganic constituents.

What, then, are the indications of the results of many years of investigation of the subject, in the field and in the laboratory, at Rothamsted?

THE EXPERIMENTS ON ROTATION MADE AT ROTHAMSTED.

The experiments have been conducted in Agdell Field. An area of 2½ acres is devoted to the purpose. The ordinary four-course rotation of—turnips, barley, clover (or beans), or fallow, and wheat, was adopted. The experiments were commenced in 1848, so that the eleventh course of four years each was completed with the harvest of 1891; and the wheat which has just been sown (October 1894) is the fourth crop of the twelfth course, and will complete the forty-eighth year of the experiments.

The area of 2½ acres was divided into three main divisions, which have, respectively, been under the following conditions as to manuring:—

1. Without manure from the commencement.

2. For the first nine courses, manured with superphosphate alone, applied only for the turnip crop commencing each course; that is, once every four years. For the tenth, and each subsequent course, salts of potash, soda, and magnesia, have been applied as well as superphosphate.

3. A complex artificial manure, also applied every fourth year; that is, for the turnips commencing each course. This manure comprises—superphosphate, salts of potash, soda, and magnesia, ammonium-salts, and rape-cake; and it supplies about 140 lb. of nitrogen per acre for the four years' course; that is, an average of 35 lb. of nitrogen per acre per annum.

The complex manure (3) was designed to be, in great measure, a substitute for farmyard manure; and it was used instead of it, in order that the amount of the different constituents supplied might be more accurately known than would have been the case if farmyard manure had been employed.

It should be further explained, that when the land is under turnips, the roots, with their leaves, are removed from one half of each of the three differently manured plots; whilst, on the other half of each, the produce is consumed on the land by sheep; or, if the weather be unsuitable for this, the roots are sliced, and both roots and leaves are spread on the land. Thus, each of the three main divisions is divided into two, making, so far, six in all.

Then again, after the first course of four years, in the third year of each course the leguminous crop was grown on only half of each of the three differently manured plots, and the other half was left fallow. Lastly, as clover cannot be relied upon on such land so often as once in four years, beans have frequently been grown instead.

We have finally, therefore, twelve plots instead of only three. That is to say, each of the three differently manured plots is divided into four as above described, and as indicated in the heading of the several Tables; and, as the same form of table will, as far as possible, be adopted throughout, it is very desirable that a clear idea of the arrangement should be formed at the outset. It will be seen that under each of the three main divisions designated in the heading according to the manuring, the results are subdivided, showing first the produce obtained where the roots were carted from the land; and secondly, where they were fed (or left) upon it. Lastly, under each of these two conditions so far as the disposal of the turnips is concerned, there is again a subdivision into two—one where in the third year of the course the land was left fallow, and the other where either clover or beans was grown.

Each year the amount of produce on each of the various plots is weighed; samples of each crop are taken; in all the dry substance and the mineral matter (ash), and in many the nitrogen, are determined; in many cases also complete analyses of the ashes of the crops have been made. Lastly, determinations of the total nitrogen have been made in the surface soils, and in the upper layers of the subsoils, at different periods; and the nitrogen as nitric acid has also been determined to a considerable depth. As to the results themselves, only brief reference to the main indications of these various investigations can be made.

Tables I., II., III., and IV. give the amounts of produce of the turnips, the barley, the leguminous crops, and the wheat, respectively, in each of the eleven years in which each was grown, in the eleven completed courses. Each Table is divided into three main divisions—the upper one giving the roots, or the grain, &c., as the case may be; the middle the leaves, or the straw; and the lower one the total produce—roots and leaves, or grain and straw, together.

The Swedish Turnip Crops.

Referring to Table I., relating to the Swedish turnips, it is seen that in the first year, 1848, there was, both without manure and with superphosphate alone, much more produce than in any subsequent year; showing that, at the commencement, the land was in somewhat high condition due to previous treatment. Then, again, as already said, for the tenth and eleventh courses, salts of potash, soda, and magnesia, were used as well as superphosphate. For these reasons, the results of

stituents being available, there was a large increase of produce due to the supply of nitrogen in the manure.

The figures in the middle division of the Table show that the produce of leaf as well as that of roots was increased by superphosphate, and that it was still further increased by the mixed manure containing nitrogen.

The next point is to consider the effects of the other conditions besides those of different manure supply; that is, the removal of the root-crop, or the feeding or the spreading of it upon the land; also whether, in the third year of each course, a leguminous crop was grown, or the land was fallowed.

It is seen that, *without manure*, whether clover or beans were grown, or the land were fallowed, there was even rather less average produce of roots over the eight years where they had been fed on the land, than where they had been carted off; but with such very small crops the differences are immaterial, if not accidental.

On the *superphosphate* plots, where the produce was much higher, and where there would, therefore, be more loss to the land by removal, the crops were materially better on the fed portions of the plots.

On the *mixed manure* plots, on the other hand, with nearly twice as much produce as with superphosphate alone, there would be still greater difference between the condition of the land where the roots were carted off and where they were fed on; but there was very little difference in the average produce of the root crop.

It will be seen further on, that the higher condition of the land where the more highly manured roots were fed upon it had a very marked effect on the succeeding cereal crops, and especially on the immediately succeeding barley. This was the case on both the superphosphate and the mixed manure plots.

The difference of effect on the average produce of the root-crop, by fallowing, or by growing beans or clover, in the third year of each course is, in the comparable cases, practically immaterial under each of the three different conditions as to manuring.

Before passing from Table I. it is to be observed that there was higher average produce over the tenth and eleventh courses with superphosphate and potash, soda, and magnesia, than over the preceding eight courses with superphosphate alone. But, as there was also increase in a greater degree with the mixed mineral and nitrogenous manure over the two than over the eight years, it is obvious that the character of the seasons had a good deal to do with the result. It is noticeable, however, that on the plots with potash, soda, and magnesia, as well as superphosphate, in

the first and of the tenth and eleventh courses are excluded from the averages to which attention will chiefly be confined. In this Table, however, as well as in those relating, respectively, to the barley and the wheat, averages are given at the foot of each division of the Tables, not only for the eight intermediate courses—second to ninth, but also for the two succeeding courses —tenth and eleventh, for which potash, soda, and magnesia were used as well as superphosphate. But, for the leguminous crops, the averages are, for reasons that will be explained, taken differently.

The first point to notice in the results is that, under each condition as to manuring, there is very great variation in the amount of produce from year to year according to the seasons. Thus, in 1868, the crop entirely failed on all the plots, although seed was sown twice. Again, whilst the complex manure containing nitrogen yielded more than 22 tons of roots in 1880, the same manure gave little more than 4 tons in 1860; the average yield over the eight courses being about 13¼ tons. Against this, the average by superphosphate alone ranged from about 6½ to about 7½ tons; whilst without manure there was an average of only about 1 ton.

Referring to this last result, it is particularly to be observed that this assumed restorative crop yields practically no produce at all when grown without manure.

The plot with superphosphate alone gives very much more than that without manure, but still very much less than an average agricultural crop. The increase, such as it was, was largely due to the greatly increased development of feeding-root within the surface-soil under the influence of the phosphatic manure; and the necessary nitrogen, beyond the small amount of combined nitrogen annually coming down in rain and the minor aqueous deposits from the atmosphere, has doubtless been gathered under the influence of the increased root-development from the previous accumulations within the soil itself. There is, in fact, perhaps no agricultural practice by which what is termed the *condition* of land, that is the readily available fertility due to recent accumulations, can be so rapidly exhausted as by growing turnips on it by superphosphate alone—provided of course that the seasons are favourable.

Compared with the produce with superphosphate alone, the mixed manure, supplying, besides superphosphate, not only salts of potash, soda, and magnesia, but a liberal amount of nitrogen, yielded, on the average of the eight courses, nearly twice as much, or between 13 and 14 tons of roots; though, as already pointed out, it yielded in some seasons over 20 tons per acre. There can be no doubt that, the necessary mineral con-

stituents being available, there was a large increase of produce due to the supply of nitrogen in the manure.

The figures in the middle division of the Table show that the produce of leaf as well as that of roots was increased by superphosphate, and that it was still further increased by the mixed manure containing nitrogen.

The next point is to consider the effects of the other conditions besides those of different manure supply; that is, the removal of the root-crop, or the feeding or the spreading of it upon the land; also whether, in the third year of each course, a leguminous crop was grown, or the land was fallowed.

It is seen that, *without manure*, whether clover or beans were grown, or the land were fallowed, there was even rather less average produce of roots over the eight years where they had been fed on the land, than where they had been carted off; but with such very small crops the differences are immaterial, if not accidental.

On the *superphosphate* plots, where the produce was much higher, and where there would, therefore, be more loss to the land by removal, the crops were materially better on the fed portions of the plots.

On the *mixed manure* plots, on the other hand, with nearly twice as much produce as with superphosphate alone, there would be still greater difference between the condition of the land where the roots were carted off and where they were fed on; but there was very little difference in the average produce of the root crop.

It will be seen further on, that the higher condition of the land where the more highly manured roots were fed upon it had a very marked effect on the succeeding cereal crops, and especially on the immediately succeeding barley. This was the case on both the superphosphate and the mixed manure plots.

The difference of effect on the average produce of the root-crop, by fallowing, or by growing beans or clover, in the third year of each course is, in the comparable cases, practically immaterial under each of the three different conditions as to manuring.

Before passing from Table I. it is to be observed that there was higher average produce over the tenth and eleventh courses with superphosphate and potash, soda, and magnesia, than over the preceding eight courses with superphosphate alone. But, as there was also increase in a greater degree with the mixed mineral and nitrogenous manure over the two than over the eight years, it is obvious that the character of the seasons had a good deal to do with the result. It is noticeable, however, that on the plots with potash, soda, and magnesia, as well as superphosphate, in

the two courses, there was a higher produce of roots on the plots where beans or clover were grown than on those that were fallowed; a result doubtless due to the increased growth of the leguminous crop under the influence of the potash manuring, and

SWEDISH TURNIPS.

GROWN IN FOUR-COURSE ROTATION, IN AGDELL FIELD.
45th year, 1892. *First Crop, Twelfth Course.*

UNMANURED CONTINUOUSLY.
Crop of roots, 1892 : 8¼ cwts. per acre.

MINERAL MANURE, COMMENCING EACH COURSE.
Crop of roots, 1892 : 11 tons 6¼ cwts. per acre.

MINERAL AND NITROGENOUS MANURE, COMMENCING EACH COURSE.
Crop of roots, 1892 : 24 tons 18 cwts. per acre.

to accumulation of nitrogen in the soil thereby. It may further be observed (though not shown in the Table) that in 1892—that is the first year of the twelfth course—the produce of the manured plots was generally higher than in either of the two preceding courses.

The accompanying figures represent selected typical Swedish turnip-plants, grown in 1892—without manure, with the mixed mineral manure alone, and with the mixed mineral and nitrogenous manure. Each plant was fixed upon a scaled background and so photographed, and the figures as given are about one-twentieth natural size, and strictly comparable. The quantities of produce recorded show that without manure it was less, but that by each of the two descriptions of manure it was considerably more, than the average of the preceding courses; and both the reversion to the uncultivated condition without manure, and the increased growth under the influence of each of the manures, are strikingly illustrated, both by the figures and by the amounts of produce given. Indeed, the results conclusively show how artificial a product is the cultivated root-crop, and how dependent it is for its successful growth on an abundant supply of available food—nitrogenous as well as mineral—within the soil.

The Barley Crops.

Table II. gives the produce of barley, the second crop of the course, and therefore always succeeding the roots, in each of the eleven years in which it was grown, in precisely the same form as that of the Swedish turnips recorded in Table I.: the upper division giving the grain per acre, the middle division the straw, and the lower one the total produce, grain and straw together.

As in the case of the root-crops, so in that of the barley, the produce in the first course is excluded from the calculation of the averages to which reference will chiefly be made. Indeed, the results of the first year of barley confirm the conclusion that the land was in somewhat high condition due to recent accumulations. The produce of the tenth and eleventh courses is also excluded from the averages, on account of the change of manure on the superphosphate plot for the tenth and succeeding courses.

Referring, however, first to the results of each of the eleven years, it is seen that, under each condition of manuring, or other treatment, there is very great variation in the amount of produce from year to year, due to variations in the characters of the seasons. Thus, without manure, the average produce over the eight courses was about 30 bushels per acre, whilst in 1857 it was in each case more than 40 bushels, and in some considerably more; but in 1869 and in 1873 it was not much over 20 bushels, and in the last two courses considerably less than 20. A glance down the columns recording the produce on the manured plots will show that in their case also there was a wide range in amount above and below the averages, according to season.

Referring now to the average produce of the eight courses (second to ninth), the first point to notice is, that whilst the

TABLE II.—*Experiments on the Rotation of—Roots, Barley, Clover (or Bean or Fallow, and Wheat; in Agdell Field, Rothamsted.* 11 *courses,* 44 *years* 1848–1891.

2. BARLEY.

Years	Unmanured				Courses 1–9 superphosphate only. Courses 10 & 11 mixed mineral manure				Mixed mineral and nitrogenous manure			
	Roots carted		Roots fed		Roots carted		Roots fed		Roots carted		Roots fed	
	Fallow	Beans or clover	Fallow	Beans or clover	Fallow	Beans or clover	Fallow	Beans or clover	Fallow	Beans or clover	Fallow	Beans or clover
DRESSED GRAIN.												
	Bush.	Bush.	Bush.	Bush.	Bush.	Bush.	Bush.	Bush.	Bush.	Bush.	Bush.	Bush.
1849	33¾	44¼	44¼	48	29½	29¼	41	42¾	37	28¼	44½	42
1853	32½	34⅜	33	28¼	32	28⅜	39¼	38	37⅛	38½	37½	36
1857	43¾	48½	44½	40⅛	30¾	28½	48¾	52⅜	47½	48	65⅜	62
1861	35½	38⅜	33	29⅜	32⅜	30⅜	40⅜	42½	60¼	60⅜	57¾	58
1865	34½	39	35⅛	27¾	31½	33½	39½	41½	44⅜	47½	46⅜	45
1869	21⅜	24⅛	21	25⅜	25½	28¾	30½	33½	39¾	42¾	38¾	42
1873	20¾	23½	20¾	22⅜	22⅜	20½	27	29⅜	31⅜	31⅜	47	46
1877	23	23⅜	22½	23⅜	21	21½	31⅜	38⅜	30¾	34⅜	44½	43
1881	29½	26¾	31⅜	25¾	24½	24½	28⅜	28¾	33⅜	35⅜	47⅛	46
1885	15½	12⅛	22¾	16	12⅞	19⅞	17⅛	32½	19	34¾	32½	34
1889	15½	11	16⅞	12⅝	16⅛	21⅜	19½	29¾	20	26⅜	23¾	25
Av. 8 courses 1853–1881	30	32⅜	30⅛	28	27⅜	27⅜	35⅜	38	40½	42⅜	48¾	47
Av. 2 courses 1885 & 1889	15½	11½	19¾	14⅜	14	20⅞	18½	31⅛	19½	30½	27⅛	29
STRAW.												
	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.
1849	2,200	2,982	3,139	3,225	1,870	2,111	3,209	3,327	2,842	2,088	3,709	3,46
1853	2,187	2,430	2,210	2,077	2,003	1,873	2,729	2,756	2,595	2,604	3,323	2,98
1857	2,330	2,600	2,430	2,312	1,545	1,475	2,595	2,780	2,400	2,435	3,570	3,46
1861	2,190	2,522	2,018	1,970	1,954	2,000	2,475	2,553	3,920	3,940	4,175	3,96
1865	1,828	2,154	1,809	1,460	1,509	1,615	2,043	2,244	2,398	2,595	3,274	2,98
1869	1,628	1,948	1,648	1,944	1,873	2,025	2,265	2,401	3,064	3,309	3,344	3,23
1873	1,374	1,343	1,311	1,495	1,370	1,565	1,611	1,841	1,626	1,723	2,796	2,68
1877	1,244	1,291	1,275	1,341	1,054	1,174	1,706	1,994	1,625	1,918	2,646	2,53
1881	1,556	1,484	1,568	1,468	1,239	1,259	1,500	1,430	1,755	1,853	2,993	3,06
1885	1,518	1,270	1,768	1,379	1,043	1,441	1,480	2,358	1,528	2,461	2,778	3,35
1889	953	931	996	865	965	1,221	1,135	1,613	1,231	1,685	1,776	2,06
Av. 8 courses 1853–1881	1,792	1,971	1,784	1,758	1,568	1,623	2,116	2,260	2,423	2,547	3,253	3,16
Av. 2 courses 1885 & 1889	1,235	1,101	1,382	1,122	1,004	1,331	1,307	1,986	1,380	2,073	2,277	2,70
TOTAL PRODUCE.												
	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.
1849	4,149	5,656	5,785	6,046	3,575	3,841	5,708	5,885	5,026	3,794	6,344	6,29
1853	4,046	4,464	4,161	3,817	3,876	3,560	5,110	5,058	4 819	4,873	5,672	5,18
1857	4,777	5,337	4,912	4,558	3,272	3,076	5,326	5,741	5,091	5,168	7,281	6,89
1861	4,248	4,718	3,871	3,635	3,807	3,775	4,803	4,982	7,419	7,391	7,554	7,16
1865	3,659	4,182	3,695	2,961	3,170	3,394	4,122	4,457	4,799	5,148	5,753	5,30
1869	2,881	3,358	2,843	3,387	3.328	3,686	3.999	4,313	5,414	5,800	5,491	5,77
1873	2,596	2,717	2,536	2,814	2,713	2,875	3,209	3,575	3,412	3,573	5,478	5,05
1877	2,602	2,623	2,609	2,673	2,304	2,558	3,530	4,157	3,406	3,890	5,217	5,00
1881	3,170	2,922	3,297	2,929	2,576	2,641	3,083	3,051	3,651	3,857	5,790	5,96
1885	2,402	1,960	3,056	2,235	1,833	2,538	2,576	4,193	2,643	4,426	4,624	5,69
1889	1,789	1,510	1,898	1,530	1,775	2,402	2,248	3,250	2,362	3,134	3,045	3,46
Av. 8 courses 1853–1881	3,497	3,790	3,491	3,351	3,131	3,196	4,148	4,417	4,755	4,962	6,018	5,80
Av. 2 courses 1885 & 1889	2,095	1,735	2,477	1,882	1,804	2,470	2,412	3,722	2,503	3,780	3,835	4,57

assumed restorative crop—the roots—gave practically no produce at all without manure, the barley gave, on land unmanured for so many years, an average of rather over 30 bushels per acre. The truth is that the cultivation for the preceding roots kept the land clean, and as there was practically no produce of roots, the soil was, in point of fact, left almost fallow for the barley during the winter preceding the roots, during the root-crop period itself, and during the succeeding winter, before the sowing of the barley. There was, therefore, very good preparation for the barley. It will be seen further on that, when grown continuously without manure, both wheat and barley yield more in proportion to their respective averages under ordinary cultivation than does either of the fallow crops—the roots or the leguminous crops. Yet, the produce of barley in rotation without manure was much in excess of that when it is grown continuously; the explanation doubtless being, as above referred to, that the crop had been grown after well-cultivated bare fallow.

Next, it is to be observed that, there having been practically no crop of roots without manure, there was no material difference between the yield of the succeeding barley where the roots were carted off or where they were fed on the land.

Turning now to the produce on the four plots with superphosphate alone, it is seen that whilst the average yield of barley on the two portions from which the roots had been carted off was under 28 bushels, that on the portions where they had been fed on the land was, in one case more than 35½, and in the other 38 bushels. The effect, on the one hand of the removal of the larger crop of roots, and on the other of the retention on the land of the greater part of its constituents, is thus very evident. It is further to be remarked, that the produce of barley where the roots grown by superphosphate had been removed from the land, was even less than on the two corresponding portions of the unmanured plot. Thus, there is confirmation of the supposition that the higher crop of barley without manure was due to the previous preparation, and conservation of constituents, by fallow; and that the lower produce on the superphosphate plot where the roots had been removed was largely due to so much greater exhaustion, especially of the available nitrogen, of the surface soil.

Next it is seen that, on the plots where the mixed manure containing nitrogen had been applied for the preceding turnips, the produce of barley was on a much higher level; and it was much higher on the portions where the turnips had been fed on the land than on those from which they had been removed.

It may be observed, that the produce, even on the plots with superphosphate alone, was, where the roots had been fed on the land, about the average of the country at large under ordinary rotation—namely, from 36 to 38 bushels; whilst, on the full manured plot, the produce was much more than this—namely, in one case 40¾, and in the other 42⅜ bushels, where the roots had been removed; and where they had been fed on the land, in one case 48⅜, and in the other 47⅞ bushels.

Thus, then, the effect on the succeeding barley of the full mineral and nitrogenous manure applied for the preceding turnips is very obvious; whilst the effect, on the one hand of the removal of the root-crop, and on the other of the retention on the land of most of its constituents, is also very marked. The experimental results relating to the second crop of the course—the barley—so far fully confirm, therefore, the explanations which have been given of the beneficial effects of root-crops grown under the ordinary conditions of manuring, on the succeeding cereal grown in alternation with them.

Examination of the results relating to the quantities of straw, and of total produce (grain and straw together), as given in the middle and lower divisions of the Table, will show that they fully bear out the general conclusions that have been drawn from a consideration of the produce of the grain alone.

The Leguminous Crops (or Fallow).

Table III. gives for the third element of the typical four-course rotation—the leguminous crops—the results obtained in each of the eleven years of the forty-four in which they were grown, in exactly the same form as those previously recorded for the turnips and for the barley. But, as in some of the years clover, and in others beans, were grown, the averages are here taken, not for the eight and for the two courses, as with the other crops, but, respectively, for the four years of the eleven in which clover was grown, and for the seven in which beans were grown.

A glance at the Table brings to view some of the difficulties connected with the growth of these crops. Thus, although the scheme of the four-course rotation supposes the growth of red clover as the third crop of each course, that is once in four years, it has in fact only been grown four times in the forty-four years—namely, in the first, seventh, ninth, and tenth courses; and when it failed beans were grown instead. It is, indeed, a matter of general knowledge and experience, that it is only on a few descriptions of soil that clover can be grown so frequently

TABLE III.—*Experiments on the Rotation of—Roots, Barley, Clover (or Beans), or Fallow, and Wheat; in Agdell Field, Rothamsted.* 11 *courses,* 44 *years,* 1848–1891.

3. CLOVER (OR BEANS), OR FALLOW.

Years	Unmanured				Courses 1–9 superphosphate only. Courses 10 and 11 mixed mineral manure				Mixed mineral and nitrogenous manure			
	Roots carted		Roots fed		Roots carted		Roots fed		Roots carted		Roots fed	
	Fallow	Beans or clover	Fallow	Beans or clover	Fallow	Beans or clover	Fallow	Beans or clover	Fallow	Beans or clover	Fallow	Beans or clover
BEANS; DRESSED CORN—1854, '58, '62, '66, '70, '78, and '90. (CLOVER, 1850, '74, '82, and '86.)												
		Bush.		Bush.		Bush.		Bush.		Bush.		Bush.
1850		(clover)		(clover)		(clover)		(clover)		(clover)		(clover)
1854		5¼		5½		5⅞		10⅜		9¼		13⅜
1858		6½		5¼		6½		8⅜		12⅜		14½
1862		29		27		29½		30		43⅜		41½
1866		10½		8⅜		7⅜		10		20⅜		24½
1870		13⅜		17⅛		15⅜		15⅜		24⅜		26½
1874		(clover)		(clover)		(clover)		(clover)		(clover)		(clover)
1878		8½		7⅜		7⅜		13⅞		20½		26⅜
1882		(clover)		(clover)		(clover)		(clover)		(clover)		(clover)
1886		(clover)		(clover)		(clover)		(clover)		(clover)		(clover)
1890		7		8¼		24⅜		24		15½		16?
Average 7 courses, beans, 1854, '58, '62, '66, '70, '78, and '90		11⅜		11⅜		13⅞		16½		20⅞		23⅜
BEANS; STRAW—1854, '58, '62, '66, 70, '78, and '90. (CLOVER, 1850, '74, '82, and '86.)												
		lb.		lb.		lb.		lb.		lb.		lb.
1850		(clover)		(clover)		(clover)		(clover)		(clover)		(clover)
1854		1,055		953		1,103		1,378		1,355		1,605
1858		1,100		965		1,155		1,320		1,520		1,760
1862		1,840		1,845		2,150		2,155		3,280		2,945
1866		1,013		905		978		1,835		1,990		2,155
1870		738		710		768		878		1,056		1,008
1874		(clover)		(clover)		(clover)		(clover)		(clover)		(clover)
1878		740		775		1,045		1,350		1,655		1,880
1882		(clover)		(clover)		(clover)		(clover)		(clover)		(clover)
1886		(clover)		(clover)		(clover)		(clover)		(clover)		(clover)
1890		603		633		1,764		1,630		1,102		1,059
Average 7 courses, beans, 1854, '58, '62, '66, '70, '78, and '90		1,013		969		1,280		1,507		1,708		1,773
CLOVER (AS HAY)—1850, '74, '82, and '86. BEANS (CORN and STRAW)—1854, '58, '62, '66, '70, '78, and '90.												
	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.
1850	(6,440)	(5,920)	(7,027)	(5,413)	(6,799)	(6,329)	(6,739)	(5,580)	(7,697)	(6,920)	(7,275)	(6,753)
1854		1,445		1,367		1,534		2,124		2,065		2,514
1858		1,515		1,307		1,605		1,895		2,357		2,754
1862		3,661		3,546		4,040		4,027		5,990		5,520
1866		1,689		1,485		1,463		2,481		3,342		3,782
1870		1,591		1,854		1,778		1,867		2,664		2,746
1874		(2,838)		(2,497)		(5,093)		(6,186)		(7,904)		(7,708)
1878		1,301		1,255		1,557		2,241		2,963		3,617
1882		(2,935)		(2,492)		(6 700		(7,927)		(8,882)		(9,374)
1886		(1,285)		(1,305)		(4 925		(4.695)		(3,255)		(3,645)
1890		1.079		1,197		3,441		3,269		2,145		2,195
Average 7 courses, beans, 1854, '58, '62, '66, '70, '78, and '90,		1,754		1,716		2,203		2,558		3,075		3,308
Average 4 courses, clover, 1850, '74, '82, and '86		3,245		2,927		5,762		6,097		6,740		6,870

as every fourth year; and in many cases it is not attempted to grow it more than once in eight years. The difficulty of growing red clover or beans frequently on ordinary arable land has been very fully illustrated in our experiments on the growth of leguminous crops. On the other hand, it has been found that red clover may be grown for many years in succession on rich garden soil; and, further, that on ordinary arable land where clover had entirely failed, some other Leguminosæ, having more extended root range, or more powerful root habit, grew luxuriantly, and yielded large crops, containing large amounts of nitrogen, for a number of years in succession. Lastly, in another field, where beans had frequently failed, red clover was afterwards sown, and gave unusually large crops.

Referring to the results in Table III., it is seen that when clover was grown in 1850, that is in the first course, and when it had not been grown on the same land for many years, large crops were obtained on all the plots; though the larger where the mixed manure including potash, and also nitrogen, had been applied for the root-crop three years previously. For the second, third, and fourth courses, clover was sown with the preceding barley, but in all three it failed in the winter, and beans were grown instead; that is, in 1854, 1858, and 1862. After these repeated failures, clover was not sown for the fifth and sixth courses, but beans were taken instead, in 1866 and in 1870. In the seventh course, clover was sown again, with the barley, and gave three cuttings in 1874; that is, twenty-four years since the last good crop. Without manure, the produce was, however, not much more than one ton per acre; with superphosphate it was much more; and with the mixed manure, including potash, much more still—corresponding to about 3½ tons of clover hay. For the eighth course clover was not sown, but beans were taken in 1878. For the ninth and tenth courses, however, clover was again sown, yielding in the ninth (1882) even more than in 1874; but in the tenth (1886) very much smaller crops, though more with mineral manure alone, now including potash, than with the mixed manure containing nitrogen also. Lastly, for the eleventh course, clover was again sown with the barley, but failed, and in 1890 beans were grown instead; the crops, as in the case of the clover in the tenth course, being greater with mineral manure alone (now including potash) than with the mixed manure containing nitrogen also.

Thus, in only four out of the eleven years in which clover should have been grown, was any crop obtained, and beans had to be taken in the other seven. The produce of clover is given

in the lower division of the Table, side by side with the total produce (corn and straw) of the *beans*; and the results for the clover are entered in parentheses.

Briefly to summarise the results given in the Table, it may be stated that the average produce of clover, reckoned as hay, was, without manure, rather over 3,000 lb.; with the superphosphate (in the last year with potash, soda, and magnesia also) nearly 6,000 lb.; and with the mineral and nitrogenous manures together for each course, about 6,800 lb. With the mineral manure alone, therefore, there was about twice as much, and with the mineral and nitrogenous manures together, considerably more than twice as much, as without manure. Compared with these amounts of clover reckoned as hay, the seven bean crops (corn and straw together) gave an average of about 1,700 lb. without manure, of nearly 2,400 lb. with mineral manure alone, and about 3,200 lb. with the mineral and nitrogenous manures together.

Not only, therefore, was the average produce of the bean crop very much less than that of the clover, but in point of fact it was only in one year, 1862, that anything like a really good crop of beans was obtained. It may be added, though the point will be further illustrated presently, that the crops of the four years of clover contained, even without manure, about as much nitrogen as, and with each of the two manures considerably more than, those of the seven years of beans. In fact, the average produce of the bean crop, and of nitrogen in it, was very much less than in the case of the clover. Nevertheless, even the average yield of nitrogen was much more in the beans than in either of the cereals with which they were grown in alternation. Thus, without manure, the four clover crops gave an average of 60·2 lb. of nitrogen per acre, and the seven bean crops 34·9 lb.; but over the eleven courses the barley gave an average of only 28·0 lb., and the wheat of only 31·7 lb. With mineral manure alone, the average yield of nitrogen was, in the clover 119·2 lb., in the beans 49·2 lb., in the barley only 27·7 lb., and in the wheat only 39·3 lb. Lastly, with mineral and nitrogenous manure together, the clover gave an average yield of nitrogen of 134·6 lb., the beans of 64·1 lb., the barley 41·2 lb., and the wheat 43·5 lb. There can, indeed, be no doubt, that the leguminous crops, and especially the clover, growing on land in the same condition, and similarly manured, have the power of taking up much more nitrogen over a given area from some source, than the cereals with which they are interpolated; and that the beneficial effects of the growth of such crops in rotation with the cereals are intimately connected with this capability.

Before passing from the results in Table III. it may be observed that, both with mineral manure alone, and with mineral and nitrogenous manure together, there is rather more produce, both of the clover and of the bean crop, where the roots had been fed upon the land, than where they had been carted off; that is the higher the condition of the land. Thus, then, the effects of the treatment of the first crop of the course —the roots—on the produce of the third or leguminous crop are clearly shown.

As already referred to, in the second and subsequent courses, when the third year came round each plot was divided, clover or beans being grown on one half, and the other half left fallow. We have, therefore, the means of comparing the effects on the other crops of the rotation—of fallow on the one hand, which of course removes nothing (though there may be the more loss by drainage), and of growing beans or clover on the other, a characteristic of which is the assimilation, and consequently the removal in the crops, especially of large amounts of nitrogen, but of other constituents also; at the same time, however, leaving in the land more or less of nitrogenous crop-residue. Such a comparison obviously has a special interest, since it is chiefly as a substitute for fallow that the growth of leguminous crops has been introduced into our rotations.

The Wheat Crops.

Table IV. records the results obtained with the fourth element of the rotation—the wheat—exactly in the same form as in the case of the other crops.

Looking first to the figures relating to the individual years, it is seen that, under each condition of manuring or other treatment, there is an enormous variation in the amount of produce in the different years, according to the seasons. Thus, taking for illustration the results in the first column under each of the three main conditions as to manuring, that is where the roots were carted from the land, and where in the third year of the course it was left fallow, there was, without manure, only 10⅛ bushels of wheat in 1879, but 45 bushels in 1863; on the superphosphate plot there was in 1879 only 14¾ bushels, and 46 bushels in 1863; and on the mixed manure plot only 12⅜ bushels in 1879, but 52½ bushels in 1863. Or, comparing the quantities of total produce, corn and straw together, which more directly represent the amounts of growth, we have, on the same plots, without manure, 2,162 lb. per acre in 1879, and 7,446 lb. in 1863; on the superphosphate plot 2,905 lb. in 1879, and

TABLE IV.—*Experiments on the Rotation of—Roots, Barley, Clover (or Beans), or Fallow, and Wheat; in Agdell Field, Rothamsted.* 11 *courses,* 44 *years,* 1848–1891.

4. WHEAT.

Years	Unmanured				Courses 1–9 superphosphate only. Courses 10 and 11 mixed mineral manure				Mixed mineral and nitrogenous manure			
	Roots carted		Roots fed		Roots carted		Roots fed		Roots carted		Roots fed	
	Fallow	Beans or clover	Fallow	Beans or clover	Fallow	Beans or clover	Fallow	Beans or clover	Fallow	Beans or clover	Fallow	Beans or clover
DRESSED GRAIN.												
1851	Bush. 30½	Bush. 28½	Bush. 31½	Bush. 30⅞	Bush. 31⅜	Bush. 28	Bush. 32½	Bush. 32	Bush. 30⅞	Bush. 28⅞	Bush. 27⅛	Bush. 31⅜
1855	37⅜	35½	37½	34½	38⅞	35½	37⅜	36⅜	38½	37⅜	37⅜	40¼
1859	35⅜	35½	35½	30½	37⅛	34⅜	39⅜	37½	42⅜	39¾	40½	38⅝
1863	45	34⅛	42	30⅜	46	34⅛	42½	41⅛	52⅛	46⅜	49	44⅜
1867	27½	21	23⅜	15½	26½	19⅜	27½	25	22⅜	23⅜	19⅝	21½
1871	14½	20⅜	14½	21⅜	16½	23⅝	15½	23	17⅜	24	17½	25½
1875	24⅜	21⅜	24½	19⅜	28⅞	28½	30½	31⅜	29⅛	31⅞	30	30½
1879	10⅜	10⅜	11⅜	8⅞	14⅜	14⅜	14½	15½	12⅜	13	10⅜	14
1883	33¼	29⅜	34½	25⅜	38½	36½	40¼	40	37½	45⅛	39½	50½
1887	34⅜	25⅝	33½	27½	41⅜	42½	40½	44⅜	39½	42½	41	43½
1891	32	29½	31½	26½	36	42½	40	50½	41	44⅜	45½	42
Av. 8 courses 1855 to 1883	28⅛	26	27⅞	23½	30⅜	28½	31½	31⅜	31½	32⅝	30½	33½
Av. 2 courses 1887 and 1891	33⅜	27½	32⅜	26⅞	38¾	42½	40½	47½	40½	43⅜	43½	42⅜
STRAW.												
1851	lb. 3,273	lb. 3,431	lb. 3,498	lb. 3,760	lb. 3,497	lb. 3,371	lb. 3,834	lb. 4,014	lb. 3,610	lb. 3,552	lb. 3,969	lb. 4,035
1855	4,295	3,619	4,070	3,351	4,286	3,525	4,492	3,611	4,952	3,942	5,107	4,370
1859	4,315	4,030	4,045	3,358	4,310	3,930	4,720	4,320	5,330	4,610	5,545	4,955
1863	4,563	3,468	4,295	3,008	4,690	3,390	5,051	3,888	5,495	4,698	5,638	4,919
1867	2,654	2,143	2,598	1,524	2,774	1,966	2,989	2,648	2,850	3,003	2,905	1,654
1871	2,075	2,799	1,946	2,655	2,128	3,048	2,240	2,980	2,628	3,440	2,863	3,644
1875	2,833	2,430	2,851	2,353	3,230	3,536	3,525	3,928	3,623	4,685	4,085	4,385
1879	1,493	1,324	1,612	1,219	1,956	1,771	1,843	1,771	1,691	1,658	1,426	2,138
1883	2,994	2,280	3,231	2,060	3,686	3,021	4,110	3,275	3,689	4,024	4,028	4,505
1887	2,505	1,859	2,655	1,844	3,465	3,298	3,480	3,468	3,308	3,423	3,763	3,645
1891	2,941	2,598	2,898	2,318	3,586	3,995	4,103	5,017	4,288	4,575	4,938	4,309
Av. 8 courses 1855 to 1883	3,153	2,762	3,081	2,441	3,383	3,023	3,621	3,303	3,782	3,758	3,950	3,821
Av. 2 courses 1887 and 1891	2,723	2,229	2,777	2,081	3,526	3,647	3,792	4,243	3,798	3,999	4,350	3,977
TOTAL PRODUCE.												
1851	lb. 5,290	lb. 5,389	lb. 5,584	lb. 5,855	lb. 5,617	lb. 5,253	lb. 6,062	lb. 6,176	lb. 5,642	lb. 5,500	lb. 5,801	lb. 6,169
1855	6,735	5,859	6,473	5,526	6,756	5,789	6,961	5,921	7,428	6,371	7,499	6,992
1859	6,582	6,262	6,270	5,265	6,671	6,120	7,242	6,689	8,066	7,154	8,136	7,417
1863	7,446	5,621	6,999	4,941	7,626	5,619	8,194	6,562	8,837	7,627	8,747	7,721
1867	4,330	3,473	4,126	2,506	4,420	3,222	4,702	4,242	4,328	4,567	4,180	3,023
1871	3,004	4,092	2,840	3,994	3,133	4,521	3,193	4,404	3,747	4,942	3,925	5,236
1875	4,412	3,784	4,396	3,642	5,065	5,328	5,443	5,954	5,448	6,699	5,942	6,292
1879	2,162	1,987	2,351	1,800	2,905	2,729	2,755	2,781	2,478	2,493	2,100	3,034
1883	5,140	4,175	5,445	3,741	6,208	5,400	6,778	5,901	6,132	6,921	6,536	7,743
1887	4,689	3,483	4,811	3,550	6,103	5,994	6,105	6,332	5,894	6,103	6,410	6,409
1891	4,868	4,371	4,763	3,921	5,742	6,546	6,509	8,034	6,748	7,250	7,610	6,811
Av. 8 courses 1855 to 1883	4,976	4,407	4,863	3,927	5,348	4,841	5,658	5,307	5,808	5,847	5,883	5,932
Av. 2 courses 1887 and 1891	4,779	3,927	4,787	3,736	5,923	6,270	6,307	7,183	6,321	6,677	7,010	6,610

7,626 lb. in 1863; and lastly, on the mixed manure plot, only 2,478 lb. in 1879, but 8,837 lb. in 1863.

The cases cited are those of the most extreme fluctuations due to season; but a glance at the columns will show that there were very considerable variations in other years, under each condition as to manuring, or other treatment; whilst the amounts of the variations differ more or less under the different soil conditions. It will be obvious, therefore, that if we would fairly compare with one another the effects of the varying conditions, it is important to take the average results of a sufficient number of years to eliminate the influence of the varying seasons. Most of our illustrations will, therefore, be drawn from the average results over the eight years of wheat in the second to the ninth courses; but some reference will also be made to the averages for the tenth and eleventh courses.

Let us first compare the average amounts of produce of grain under the three main conditions as to manuring, excluding, however, those obtained on the portion of the unmanured plot where the roots were fed on the land, and where beans or clover were grown in the third year of each course; as the crops, especially of the barley and of the wheat, were somewhat adversely affected by a dell on one side of the plot, the surface soil being in consequence comparatively shallow. The figures show that, on the three portions, the produce ranged, without manure, from 26 to 28½ bushels; with superphosphate from 28½ to 31¾; and with the mixed manure from 30½ to 33¼ bushels. Or, taking the amounts of total produce (grain and straw together), the range of amounts is—without manure from 4,407 to 4,976 lb.; with superphosphate from 4,841 to 5,658 lb.; and with the mixed manure from 5,808 to 5,932 lb. There is, therefore, both in grain and in total produce of the fourth crop of the course, an obvious difference, but certainly less than might have been expected, due to the varying conditions as to manuring in the first year, separated from the fourth by the growth and removal of the intermediate crops.

Next, comparing the effects on the fourth crop—the wheat—of the removal of the first—the turnips—or the retention of them, or of most of their constituents, on the land, it is seen that without manure, under which conditions there were practically no roots grown, the difference of result from removal or otherwise is quite immaterial, and is probably accidental. With superphosphate alone, and more roots grown, the nitrogen of which was doubtless obtained from previous accumulations within the soil, the removal or the retention on the

land of the constituents of the turnips should, therefore, more materially affect the condition of the soil for the growth of the succeeding crops. It was shown that the effect was very marked on the barley which immediately succeeded the roots. There was also somewhat less produce, both of clover and of beans, where the roots had been removed; and now, in the case of the fourth crop—the wheat—there is still distinct effect. Thus, taking the fallow portions, there was an average of 30¾ bushels of wheat where the roots had been removed, and 31¾ bushels where they were fed or retained on the land; the corresponding amounts of total produce being 5,348 lb. and 5,658 lb. Or, taking the produce on the bean and clover portions, there were 28½ bushels of grain where the roots had been removed, and 31⅜ bushels where they had not been removed; the corresponding amounts of total produce being 4,841 lb. and 5,307 lb. Lastly, with the mixed manure, including nitrogen, the average produce was, on the fallow portions, 31½ bushels after the removal of the roots, but only 30½ where they had not been removed; the amounts of total produce being, however, 5,808 lb. and 5,883 lb. On the bean or clover portions, the results were 32⅝ bushels where the roots were carted, and 33¼ bushels where they were not removed; and the amounts of total produce were 5,847 and 5,932 lb.

Reference to the average produce of the last two courses, the tenth and eleventh, the wheat years of which were of more than average productiveness, shows, in the case of the manured plots, more striking difference in the amount of the fourth crop due to the removal or the retention on the land of the constituents of the first crop—the roots. The roots of those courses were, however, more than average in amount.

The results, both with superphosphate alone, and with the mixed manure, afford, therefore, distinct evidence of the effect of the removal or otherwise of the first crop of the course—the turnips—not only on the second and third crops, but on the fourth crop—the wheat—also.

The next point is to illustrate the difference of effect on the other crops of the rotation, on the one hand of the growth and removal of the highly nitrogenous leguminous crop, and on the other of fallowing which removes nothing; and first as to the wheat, which we are now specially considering, and which immediately succeeds the leguminous crop or the fallow.

A careful examination of the average results over the eight courses (second to ninth) will show that, both without manure, and with superphosphate alone, that is under conditions of exhaustion, especially of available nitrogen, the wheat crops were

in every case higher after fallow, with its supposed accumulation, than after the leguminous crops, which removed much more nitrogen than the succeeding wheat would require. On the other hand, on the mixed manure plots, where the condition of the land, and especially its nitrogenous condition, was not exhausted, but fairly maintained, there was even rather more average produce of wheat after the removal of the highly nitrogenous leguminous crops than after the accumulations of the fallow.

It is unsafe to form general conclusions from the results of individual years, since the characters of the seasons may have so much influence. But it may be observed that, after the heavy crops of clover on the superphosphate plots in 1882, and more where the roots were fed than where they had been removed, the wheat crops of the next year, 1883, which were higher than average, were lower after the leguminous crop than after fallow; whilst, on the highly manured plot, they were much the higher after the leguminous crop. In the tenth course, however, after the use of potash as well as superphosphate, there were fair but by no means such heavy crops of clover as in the very favourable season of the preceding course, and there was less where there had then been the larger crop; and in the eleventh course also, there was less total produce of beans where the heavier crop of clover had been grown in the ninth course. The result was, that on the average of the last two courses, the wheat gave less instead of more total produce after fallow than after the leguminous crops; but more where the roots had been fed than where they had been carted; that is, more where the land was the less exhausted.

The general result is, that where there was not exhaustion, but accumulation due to manure and to increased crop residue, the growth and removal of the leguminous crops not only gave large amounts of nitrogen in the removed crops, whilst the fallow yielded none, but also left more available nitrogen for the succeeding wheat than was rendered available (and remained) from the resources of the soil after the fallow. In other words, not only were the nitrogen and other constituents obtained in the leguminous crops an entire gain compared with the result of fallow, but, on the average of years, a somewhat larger succeeding wheat crop was obtained as well.

Here, then, is a striking illustration of the advantages of the interpolation of leguminous crops instead of fallow with the cereals in our rotations; and it is seen that the benefit may be the greater if the land be not abnormally exhausted, as was the case on the continuously unmanured, and on the superphosphate plots.

Although there was thus great difference between the effects,

on the one hand, of the growth and removal of a leguminous crop, and on the other of fallow, so far as the third year of the course is concerned; yet, where the manurial conditions were not defective, there was even more wheat succeeding the leguminous crop, than succeeding the fallow. The influence of the conditions of the third year of the course does not, however, seem to extend in any marked degree to the crops succeeding the wheat; that is, to the roots commencing the next course, and to the barley succeeding the roots.

So far as the roots are concerned, the average results over the eight courses show, both without manure and with superphosphate alone, that is on the most exhausted plots, that the advantage, if any, is more with the fallow than with the leguminous plots; whilst, with the full manure, there is scarcely any difference of result clearly traceable to the treatment of the land in the third year of the preceding courses. Over the last two courses, again, without manure no benefit accrued to the root-crop by the growth of the leguminous crop as compared with fallow. On the superphosphate plots, however, now with potash, soda, and magnesia, as well, and doubtless more leguminous produce accordingly, there were more roots on the leguminous than on the fallow plots; but, with the full manure, there was practically no difference in the produce of roots on the fallow compared with the leguminous crop plots. Obviously, the fact that there was not materially less produce of roots where the leguminous crops had been grown and removed, as compared with where the land had been fallow, is of itself evidence of the beneficial rather than exhausting effect of their growth and removal, so far as the requirements of the succeeding crops are concerned.

Nor is the effect of the growth and removal of a leguminous crop, compared with fallow, very definite on the barley succeeding the manured roots. It is, however, over the eight courses, in favour of the growth of the leguminous crops; and, though with very small crops, it is, excepting without manure, much more so over the last two courses.

From the results as a whole it may be concluded that, where the land was the most exhausted, the growth of the leguminous crop was correspondingly limited, and, being at the expense of the little accumulation that there was, its removal further exhausted the immediately available supplies; whilst, where the accumulations were greater, the growth was dependent on a more extended root-development, and therefore greater range of collection; the luxuriance was much greater, and the surface-soil at any rate gained by an increased amount of highly nitrogenous leguminous crop-residue. It has further been seen, that

the effects of the manuring and treatment of the first crop of the course—the turnips—were manifest in the produce of the fourth crop—the wheat; and also that the effects of fallowing, or of growing and removing a highly nitrogenous crop, in the third year, were clearly traceable on the crop of the fourth year, and to some extent, though in a much less degree, on the subsequent crops commencing the next course.

The Amounts of Produce grown in Rotation, and in the various Crops grown continuously.

Obviously, when considering what are the benefits arising from rotation as distinguished from the growth of the individual crops continuously, it is desirable, as far as practicable, to compare the results of the two methods in regard to their yield per acre of some of the more important constituents of the crops. For the purposes of such a comparison, it will be of interest to illustrate the point by reference specially to the amounts of *dry matter*, *nitrogen*, *total mineral matter* (*ash*), *phosphoric acid*, and *potash* (and in some cases of lime), in the crops grown in rotation, and in those grown continuously, under as far as possible parallel conditions as to manuring. Accordingly, so far as results obtained under rotation are concerned, the amounts of each of the above constituents are calculated in the produce per acre of the respective crops, in each of the eight courses (second to ninth), under each of the twelve different conditions as to manuring, or other treatment; and the average amounts of these per acre per annum are compared with those in the individual crops grown continuously, as a rule, in the same seasons as those in which the rotation crops were obtained, and under the same, or nearly parallel, conditions as to manuring.[1]

The Amounts of Dry Matter produced in the Rotation, and in the Continuous Crops.

Table V. shows the average annual amount of *dry matter* produced per acre, in each of the four crops—roots, barley, leguminous crop, and wheat—grown in rotation, and continuously, as above described. It shows the amounts, separately in the roots, leaves, and total produce, of the turnips; in the grain, straw, and

[1] The amounts of the constituents removed per acre in the rotation crops are calculated from the results of actual analyses; and in the case of the continuously grown crops the amounts of dry matter and ash, and sometimes those of nitrogen, are also calculated from direct determinations; but generally the nitrogen, and always the phosphoric acid, potash, and lime, are calculated from the percentage composition of the rotation crops grown under parallel conditions as to manuring.

TABLE V.—*Experiments on the Rotation of—Roots, Barley, Clover (or Beans), or Fallow, and Wheat; in Agdell Field, Rothamsted. 8 courses, 32 years*, 1852-1883.

AVERAGE AMOUNTS OF *DRY MATTER* PER ACRE PER ANNUM, GROWN IN ROTATION, COMPARED WITH THOSE IN THE CROPS GROWN CONTINUOUSLY.

—		Unmanured				Superphosphate				Mixed mineral and nitrogenous manure			
		Roots carted		Roots fed		Roots carted		Roots fed		Roots carted		Roots fed	
		Fallow	Beans or clover	Fallow	Beans or clover	Fallow	Beans or clover	Fallow	Beans or clover	Fallow	Beans or clover	Fallow	Beans or clover
		SWEDISH TURNIPS.											
		lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.
Roots	Rotation	359	228	323	205	1,724	1,631	1,918	1,901	1,081	3,128	3,107	3,069
	Continuous [1]	236	236	236	236	945	945	945	945	1,876	1,876	1,876	1,876
	Rotn. + or − cont.	123	−8	87	−31	779	686	973	956	1,205	1,252	1,231	1,193
Leaves	Rotation	56	49	52	45	161	176	179	200	310	355	333	354
	Continuous [1]	49	49	49	49	142	142	142	142	345	345	345	345
	Rotn. + or − cont.	7	0	3	−4	19	34	37	58	−35	10	−12	9
Total	Rotation	415	277	375	250[2]	1,885	1,807	2,097	2,101	3,391	3,483	3,440	3,423
	Continuous [1]	285	285	285	285	1,087	1,087	1,087	1,087	2,221	2,221	2,221	2,221
	Rotn. + or − cont.	130	−8	90	−35	798	720	1,010	1,014	1,170	1,262	1,219	1,202
		BARLEY.											
Grain	Rotation	1,396	1,489	1,399	1,307	1,284	1,294	1,665	1,780	1,917	1,987	2,262	2,273
	Continuous	875	875	875	875	1,128	1,128	1,128	1,128	2,298	2,298	2,298	2,298
	Rotn. + or − cont.	521	614	524	432	156	166	537	652	−381	−311	−36	−25
Straw	Rotation	1,493	1,647	1,486	1,459	1,307	1,355	1,765	1,879	2,029	2,129	2,701	2,613
	Continuous	947	947	947	947	1,052	1,052	1,052	1,052	2,489	2,489	2,489	2,489
	Rotn. + or − cont.	546	700	539	512	255	303	713	827	−460	−360	212	124
Total	Rotation	2,889	3,136	2,885	2,766[2]	2,591	2,649	3,430	3,659	3,946	4,116	4,963	4,886
	Continuous	1,822	1,822	1,822	1,822	2,180	2,180	2,180	2,180	4,787	4,787	4,787	4,787
	Rotn. + or − cont.	1,067	1,314	1,063	944	411	469	1,250	1,479	−841	−671	176	99
		BEANS (6 COURSES), CLOVER (2 COURSES), OR FALLOW.											
Corn	Rotation		631		625		640		769		1,147		1,292
	Continuous		234		234		265		265		581		581
	Rotn. + or − cont.		397		391		375		504		566		711
Straw	Rotation		879		835		978		1,213		1,487		1,540
	Continuous		422		422		524		524		799		799
	Rotn. + or − cont.		457		413		454		689		688		741
Total	Rotation		1,510		1,460		1,618		1,982		2,634		2,832
	Continuous		656		656		789		789		1,380		1,380
	Rotn. + or − cont.		854		804		829		1,193		1,254		1,452
Clover	Rotation		2,309		1,996[3]		4,717		5,645		6,714		6,833
	Continuous		?		?		?		?		?		?
Average of 8 courses, beans and clover			1,710		1,594[3]		2,393		2,897		3,654		3,832
		WHEAT.											
Grain	Rotation	1,516	1,368	1,483	1,235	1,636	1,514	1,702	1,668	1,685	1,740	1,599	1,752
	Continuous	647	647	647	647	766	766	766	766	1,238	1,238	1,238	1,238
	Rotn. + or − cont.	869	721	836	588	870	748	936	902	447	502	361	514
Straw	Rotation	2,636	2,296	2,573	2,036	2,844	2,513	3,021	2,767	3,158	3,137	3,273	3,186
	Continuous	1,082	1,082	1,082	1,082	1,204	1,204	1,204	1,204	2,142	2,142	2,142	2,142
	Rotn. + or − cont.	1,554	1,214	1,491	954	1,640	1,309	1,817	1,563	1,016	995	1,131	1,044
Total	Rotation	4,152	3,664	4,056	3,271[3]	4,480	4,027	4,723	4,435	4,843	4,877	4,872	4,938
	Continuous	1,729	1,729	1,729	1,729	1,970	1,970	1,970	1,970	3,380	3,380	3,380	3,380
	Rotn. + or − cont.	2,423	1,935	2,327	1,542	2,510	2,057	2,753	2,465	1,463	1,497	1,492	1,558

[1] Average per acre, 19 years, 1849-52 and 1856-70.

[2] Probably crop too low owing to a dell.

total produce, of the barley, and of the wheat; in the corn, straw, and total produce, of the beans; and in the clover. It will be seen that the arrangement and headings of the columns are exactly the same as in the Tables of produce already considered; and that, for each description of crop, or part of the crop, the first line shows the amounts obtained under rotation, the second those in the crop grown continuously, and the third the difference between the two.

The Dry Matter in the Turnip Crops.—Referring first to the upper division of the Table, relating to the Swedish turnips, it should be stated that results for the crops grown continuously are not available for the same eight years as those grown in rotation; but for each of the three conditions as to manuring, the average for 19 years of growth is taken. So far as manuring is concerned, the unmanured and the superphosphate conditions were the same for the rotation and for the continuous crops. But, in the case of the mixed manure, the rotation plots received a larger amount of nitrogen for the roots; in fact, enough to carry the four crops of the course. The continuous plot, on the other hand, received a less amount each year; but, unlike the rotation plots, with no intermediate crops to use up any available residue from the previous application.

The figures show that—without manure—the difference in the amounts of dry matter produced in rotation and in continuous growth are immaterial. The utter failure in both cases without manure is confirmatory of the absolute dependence of this valuable rotation crop on supplies within the soil itself, either from accumulations, or from direct manuring.

The less produce of the continuous than of the rotation crops with superphosphate is also quite consistent with the supposition that, under such conditions, the crop greatly exhausts the available nitrogen of the soil, and especially of the surface soil.

With the mixed mineral and nitrogenous manure, again, there is also considerably less production of dry substance when the crop is grown continuously than when it is grown in rotation. The result is, however, due partly to the larger amount of nitrogen directly supplied by manure to the rotation crops as above referred to, but partly to the fact that when the same description of root-crop, with the same character and range of roots, is grown year after year on the same land, the surface-soil becomes close, and a somewhat impervious pan is formed below; conditions which are very unfavourable for a crop which pre-eminently requires a good tilth for great development of fibrous root within the soil. The results with the mixed manure are, of course, the most comparable with those of ordinary practice;

and it is clear that, however explained, much more produce is obtained under rotation than with continuous growth. It need only further be remarked that, of the total dry matter produced, there are many times as much in the edible root as in the leaf which almost wholly remains only for manure again.

The Dry Matter in the Barley Crops.—The second division of Table V. compares the amounts of dry matter yielded in *barley*, grown, respectively, in rotation, and continuously—that is, year after year on the same land. The results for the continuously grown crops relate to the average produce of the same eight seasons as those in which the rotation crops were obtained. The unmanured and the superphosphate conditions were also quite parallel in the two series of experiments. In the case of the mixed manure results, it should be borne in mind that in the rotation experiments a quantity of manure was applied for the preceding crop—the turnips—which is supposed to carry the whole of the crops of the four years' course; whilst, in the continuous experiments, the quantity of nitrogen, for example, which is applied each year for the immediate crop, amounts to rather more than one-fourth of that applied for four years in the rotation experiments.

The figures show that—without manure—there was much less dry matter in grain, straw, and total produce, in the crops grown continuously than in those grown in rotation; in fact, in the total produce only about three-fifths as much. The much higher amount under rotation is quite consistent with the explanation that in the rotation experiments without manure, the roots having failed, the barley crop had, in point of fact, the benefit of the preparation which bare fallow is known to confer.

With superphosphate alone, the continuously grown barley crops yielded more dry matter in grain, straw, and in total produce, than those without manure; the excess being largely due to increased capability of utilising the available nitrogen of the surface soil, under the influence of the phosphatic manure. Both sets of the superphosphate rotation crops yielded more dry matter than the continuous ones, the excess being, however, much less where the rotation roots had been removed than where they had been consumed or spread upon the land. The effect of the growth and accumulation by the previous root-crop, and of the more or less available manurial residue left under the different conditions, as compared with the result when the barley is grown year after year on the same land, is thus very evident.

As already said, the amount of nitrogen annually applied on the mixed manure plot was, for the continuous crops, somewhat more than one-fourth of that applied for the preceding root-crops in the case of the rotation plots. Under these circumstances,

the amounts of dry matter in grain, straw, and total produce, were considerably less in the barley grown in rotation where the roots and leaves of the turnips had been removed than in that grown continuously; but where in the case of the rotation barley the root-crops had been consumed or spread upon the land, the average yield of dry matter per acre was much more nearly identical under rotation and under continuous cropping; though upon the whole it was more under rotation. The effects on the second crop of the course, of the manurial and other treatment of the first crop, are here, then, further illustrated. Lastly, it is to be observed, that a larger proportion of the total dry matter of the crop is, on the average, accumulated in the straw which is generally retained on the farm, than in the grain which is, as a rule, exported from it.

Thus, both the actual and the comparative results clearly show, that the successful growth of the barley was directly dependent on the supplies within the soil, and that the object may be gained, either in a properly manured rotation, or by the direct application of suitable manures, including a liberal supply of nitrogen for the immediate crop. Having regard to the general economy of the farm, the former plan is as a rule the most advantageous; though, owing to the success with which the crop can be grown by direct artificial manures, such manures are often used as supplements; or, sometimes, a barley crop is taken after another cereal, by the aid of artificial manures alone.

The Dry Matter in the Leguminous Crops.—The third division of the Table (V.) shows the average amounts of dry matter per acre per annum in the corn, straw, and total produce, of the six crops of beans grown in rotation in the eight years; also the average amounts in the same six years when the crop was grown continuously in another field. Below the bean results are given the average amounts per acre per annum in the clover grown in rotation in the remaining two of the eight years; and there are also given the average amounts over the eight years, in the six crops of beans and two of clover. It will be seen, however, that there is no entry in the line for continuous crops of clover, for the simple reason that, as has been shown in various papers, it was found impossible to grow clover year after year on ordinary arable land.

The figures show that, meagre as was the average produce of dry matter in the crops of beans, even when grown in rotation, they were much less still when grown continuously. This was the case whether we look to the amounts in the corn, the straw, or the total produce. Indeed, the lines of total produce show that the average amounts in the continuously grown crops were, under each condition of manuring or other treatment, less than half as much as those grown in rotation. In both cases, there

was somewhat more with superphosphate than without manure, and more still with the mixed manure, including both potash and nitrogen, but even under these conditions, and in rotation, the produce was very small.

Under each condition as to manuring, the produce of dry matter in the clover grown in rotation was more, and in some very much more, than in the beans so grown. Without manure, it averaged only about 1 ton per acre per annum; with superphosphate, in one case more than 2, and in the other more than 2½ tons; and in each with the full manure, including potash and nitrogen, more than 3 tons.

Lastly, the average production of dry substance in the six crops of beans and two of clover taken together was—without manure only about ¾ ton; with superphosphate, in one case little more than 1 ton, and in the other rather more than 1¼ ton; and, with the mixed manure, in both cases less than 1¾ ton. These amounts in the leguminous crops with the mixed manure were, however, greater than those obtained in the turnip crops, but less than those in either the barley or the wheat grown in rotation. The significance of the amounts grown in the leguminous crops will, however, be the more clearly recognised when we come to consider the quantities of nitrogen in the different crops; and also the fact of the large proportion of the manurial constituents of the leguminous crops grown in rotation, that will generally be retained on the farm.

The Dry Matter in the Wheat Crops.—The bottom division of the Table (V.) shows the average amounts of dry substance in the wheat—grain, straw, and total produce—grown in rotation, and those obtained in the same years in another field under as far as possible parallel conditions as to manuring, but grown continuously; that is, year after year on the same land.

A glance at the figures shows that, both without manure and with superphosphate alone, the amount of dry matter produced was, both in grain and straw, in each case considerably less than half as much in the crops grown continuously as in those grown in rotation; and that, even with the mixed manure, supplying both mineral constituents and nitrogen, it was considerably less in the continuous than in the rotation crops.

So far as the unmanured and the superphosphate crops are concerned, it is obvious that the growth year after year must be much more exhausting, both of nitrogen and of certain essential mineral constituents, in a condition of composition and of distribution within the soil and subsoil available to one particular crop, than when the crop is grown in alternation with others, of different requirements, habits, and root-ranges.

It has been explained that in the case of the mixed manure rotation plots there was applied for the first crop of the course, besides a full supply of mineral constituents, about 140 lb. of nitrogen; at the average rate, therefore, of 35 lb. per acre per annum over the four years. But, in the case of the continuously grown wheat crops, not only a full supply of mineral manure, but 43 lb. of nitrogen as ammonium-salts, was directly applied every year. The fact of the greater amount of produce on the rotation plots would indicate, therefore, that notwithstanding the growth and removal of the intermediate crops since the application of the manure for the roots, there was more nitrogen, and more of other constituents also, in a condition of composition and of distribution available for the wheat, than in the case of the annual direct supply.

Of course, the proportion of grain and of straw in a wheat crop varies, as it also does in barley, according to variety, soil, season, and other circumstances. It is seen that, in the experimental crops, whether grown in rotation or continuously, there was always much more of the produced dry matter accumulated in the straw than in the grain. Indeed, there was in some cases nearly twice as much. On the assumption, therefore, that as a rule the grain will be sold, and the straw retained on the farm as food and litter, very much more than half of the produced dry matter will be so retained.

Comparing the amounts of dry matter accumulated in the different rotation crops, and taking as the most normal the quantities obtained under the influence of the mixed manure, including nitrogen, it is seen that, on the average, the two cereal crops—the barley and the wheat—produced approximately equal amounts; and each considerably more than either of the fallow crops—the roots or the Leguminosæ.

The Amounts of Nitrogen in the Rotation, and in the Continuous Crops.

Table VI. shows the average amounts of nitrogen per acre per annum, over the eight years, in the rotation, and in the continuous crops, respectively.

The Nitrogen in the Root-crops.—Without manure, with extremely small crops, but very abnormally high percentage of nitrogen in them, the amounts per acre were, in the continuously grown crops only about twice as much as annually comes down as combined nitrogen in the rain and minor aqueous deposits from the atmosphere; whilst, even in the rotation crops, the amounts averaged but little more than in the continuous.

TABLE VI.—*Experiments on the Rotation of—Roots, Barley, Clover (or Beans), or Fallow, and Wheat; in Agdell Field, Rothamsted.* 8 *courses*, 32 *years*, 1852–1883.

AVERAGE AMOUNTS OF *NITROGEN* PER ACRE PER ANNUM IN THE ROTATION CROPS, COMPARED WITH THOSE IN THE CROPS GROWN CONTINUOUSLY.

	Unmanured				Superphosphate				Mixed mineral and nitrogenous manure			
	Roots carted		Roots fed		Roots carted		Roots fed		Roots carted		Roots fed	
	Fallow	Beans or clover	Fallow	Beans or clover	Fallow	Beans or clover	Fallow	Beans or clover	Fallow	Beans or clover	Fallow	Beans or clover
SWEDISH TURNIPS.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.
Roots: Rotation	9·4	5·8	8·5	5·3	28·7	26·8	32·9	32·2	66·8	66·7	68·2	65·5
Roots: Continuous[1]	6·8	6·8	6·8	6·8	13·6	13·6	13·6	13·6	40·1	40·1	40·1	40·1
Roots: Rotn. + or − cont.	2·6	−1·0	1·7	−1·5	15·1	13·2	19·3	18·6	26·2	26·6	28·1	25·4
Leaves: Rotation	2·1	1·8	1·9	1·6	6·1	6·5	6·9	7·6	12·2	13·9	13·0	13·9
Leaves: Continuous[1]	2·0	2·0	2·0	2·0	5·8	5·8	5·8	5·8	14·1	14·1	14·1	14·1
Leaves: Rotn. + or − cont.	0·1	−0·2	−0·1	−0·4	0·3	0·7	1·1	1·8	−1·9	−0·2	−1·1	−0·2
Total: Rotation	11·5	7·6	10·4	[2]6·9	34·8	33·3	39·8	39·8	78·5	80·6	81·2	79·4
Total: Continuous[1]	8·8	8·8	8·8	8·8	19·4	19·4	19·4	19·4	54·2	54·2	54·2	54·2
Total: Rotn. + or − cont.	2·7	−1·2	1·6	−1·9	15·4	13·9	20·4	20·4	24·3	26·4	27·0	25·2
BARLEY.												
Grain: Rotation	21·5	23·0	21·5	20·1	17·8	17·8	22·9	24·6	29·7	30·7	35·0	34·9
Grain: Continuous	13·5	13·5	13·5	13·5	15·5	15·5	15·5	15·5	35·2	35·2	35·2	35·2
Grain: Rotn. + or − cont.	8·0	9·5	8·0	6·6	2·3	2·3	7·4	9·1	−5·5	−4·5	−0·2	−0·3
Straw: Rotation	6·6	7·4	6·6	6·6	5·5	5·7	7·5	7·9	9·5	10·0	12·5	11·9
Straw: Continuous	4·2	4·2	4·2	4·2	4·5	4·5	4·5	4·5	11·4	11·4	11·4	11·4
Straw: Rotn. + or − cont.	2·4	3·2	2·4	2·4	1·0	1·2	3·0	3·4	−1·9	−1·4	1·1	0·5
Total: Rotation	28·1	30·4	28·1	[2]26·7	23·3	23·5	30·4	32·5	39·2	40·7	47·5	46·8
Total: Continuous	17·7	17·7	17·7	17·7	20·0	20·0	20·0	20·0	46·6	46·6	46·6	46·6
Total: Rotn. + or − cont.	10·4	12·7	10·4	9·0	3·3	3·5	10·4	12·5	−7·4	−5·9	0·9	0·2
BEANS (6 COURSES), CLOVER (2 COURSES), OR FALLOW.												
Corn: Rotation		27·5		27·2		30·4		36·6		49·6		55·7
Corn: Continuous		9·7		9·7		10·5		10·5		21·4		21·4
Corn: Rotn. + or − cont.		17·8		17·5		19·9		26·1		28·2		34·3
Straw: Rotation		9·4		8·9		10·1		12·4		14·0		14·5
Straw: Continuous		4·6		4·6		5·5		5·5		7·1		7·1
Straw: Rotn. + or − cont.		4·8		4·3		4·6		6·9		6·9		7·4
Total: Rotation		36·9		36·1		40·5		49·0		63·6		70·2
Total: Continuous		14·3		14·3		16·0		16·0		28·5		28·5
Total: Rotn. + or − cont.		22·6		21·8		24·5		33·0		35·1		41·7
Clover: Rotation		55·0		[2]47·0		124·5		144·6		167·0		168·4
Clover: Continuous		?		?		?		?		?		?
Average of 8 courses, Beans and Clover		41·5		[2]38·9		61·5		72·9		89·5		94·7
WHEAT.												
Grain: Rotation	26·2	23·7	25·5	21·5	27·2	25·4	28·6	28·2	28·9	30·1	27·7	30·1
Grain: Continuous	11·6	11·6	11·6	11·6	13·9	13·9	13·9	13·9	25·9	23·9	23·9	23·9
Grain: Rotn. + or − cont.	14·6	12·1	13·9	9·9	13·3	11·5	14·7	14·3	5·0	6·2	3·8	6·2
Straw: Rotation	10·4	9·1	9·9	8·2	11·8	10·5	12·3	11·7	13·2	13·6	13·8	13·1
Straw: Continuous	5·4	5·4	5·4	5·4	5·9	5·9	5·9	5·9	10·1	10·1	10·1	10·1
Straw: Rotn. + or − cont.	5·0	3·7	4·5	2·8	5·9	4·6	6·4	5·8	3·1	3·5	3·7	3·0
Total: Rotation	36·6	32·8	35·4	[2]29·7	39·0	35·9	40·9	39·9	42·1	43·7	41·5	43·2
Total: Continuous	17·0	17·0	17·0	17·0	19·8	19·8	19·8	19·8	34·0	34·0	34·0	34·0
Total: Rotn. + or − cont.	19·6	15·8	18·4	12·7	19·2	16·1	21·1	20·1	8·1	9·7	7·5	9·2

[1] Calculated on average produce of 19 years, 1849–52 and 1856–70. [2] Probably crop too low owing to a dell.

With superphosphate alone, much larger crops, but much lower percentages of nitrogen, there was very much more nitrogen taken up than without manure; in fact, when grown in rotation from three to four times as much, and when grown continuously more than twice as much. There was, too, very much more in the rotation than in the continuous crops. The detailed results published elsewhere, relating to the continuous growth of root-crops afford conclusive evidence that the increased amount of nitrogen taken up by the crop under the influence of phosphatic manures is derived from the resources of the soil itself, by the aid of the greatly enhanced development of fibrous feeding root induced by such manures.

With the mixed manure containing nitrogen there was, as with superphosphate alone, much more nitrogen taken up under rotation than with continuous growth. But, under rotation, there was about twice as much taken up with the mixed manure containing nitrogen as with superphosphate without nitrogen; and with continuous growth there was nearly three times as much taken up as with superphosphate without nitrogen. It is clear, therefore, that the crops, whether grown in rotation or continuously, took up much of the nitrogen supplied by the manure. Indeed, it cannot be doubted that, beyond the small amount of combined nitrogen annually coming down from the atmosphere in rain and the minor aqueous deposits, the source of the large amount of nitrogen of root-crops is the store of it within the soil, whether this be due to accumulations, or to direct supply by manure. On the other hand, the large amounts of produce obtained by the aid of nitrogenous manures on land to which no carbonaceous manure has been applied for about fifty years is evidence that the atmosphere is at any rate the chief, if not the exclusive, source of the carbon of the crops.

Lastly, as to the results in the Table relating to the Swedish turnips, it is seen that by far the greater part of the nitrogen of the crops was accumulated in the edible root.

The Nitrogen in the Barley Crops.—The second division of Table VI. shows the average amounts of nitrogen per acre per annum over the eight years in the rotation and in the continuous barley crops respectively.

Referring to the results chiefly in their bearing on the question of the position of the barley crop in rotation, and of its dependence, or otherwise, on the soil for its supplies of nitrogen, the amounts of it in the total crops, grain and straw together, are of most interest.

When considering similar results relating to the first crop of the course—the Swedish turnips, it was seen that the average

amount of nitrogen per acre per annum in the total crops, roots, and leaves together, was only 10 or 11 lb., or even less, when grown without any manure. The results relating to the rotation barley crops show, however, that the average annual removal in them was without manure nearly 30 lb.; the conditions of growth being substantially equivalent to fallow, as practically no root-crop had been removed.

Consistently with other evidence on the point, the amounts of nitrogen removed in the barley crops grown on the superphosphate plots are seen to be even considerably less than without manure, where the increased crop of roots grown under the influence of the superphosphate had been removed from the land; but where the superphosphate turnips had been fed on the land, the amounts of nitrogen removed in the barley crops are more than under the parallel conditions without manure. In other words, an increased amount of nitrogen having been taken up from the soil by the turnips under the influence of the superphosphate, the land was left poorer in available nitrogen for the barley where the increased turnip crop had been removed from the land, but richer where it, or its manurial residue, was left upon it.

Again, under the influence of the mixed manure, supplying a liberal amount of nitrogen for the roots, which took up a considerable quantity of it, there was much less nitrogen in the succeeding barley, where the roots so grown had been removed, than where they or their manurial residue had been left on the land.

The actual quantities of nitrogen removed in the barley crops, where the roots had previously been removed, were—without manure nearly 30 lb., with superphosphate about 23½ lb., and with the mixed manure about 40 lb.; but where the roots had been fed or left on the land, they were, without manure about 28 lb., with superphosphate more than 30 lb., and with the mixed manure containing nitrogen about 47 lb.

Comparing the amounts of nitrogen taken up by the rotation, with those by the continuously grown barley, it is seen, as might be expected under the conditions described, that both without manure and with superphosphate, the rotation barley took up much more than the continuously grown. Where, however, nitrogenous manure had been applied for the roots, and they had been removed, the succeeding barley took up less nitrogen than the continuous crops which annually received nitrogenous manure; but where the roots had not been removed from the land, the nitrogen was nearly the same in the rotation as in the continuously grown barley—about 47 lb. per acre per annum.

The influence of the manuring, and of the amount and

treatment of the previous root-crop, on the available supply of nitrogen within the soil for the succeeding barley is, therefore, throughout clearly traceable.

Lastly, in regard to the nitrogen statistics of the barley crops, it is to be observed that, under whatever conditions of manuring or other treatment, and whether grown in rotation or continuously, there was generally three-fourths or more of the total nitrogen of the crop accumulated in the grain, that is, in the portion which is as a rule sold off the farm; only about one-fourth, therefore, remaining in the straw which is supposed to be retained on the farm.

The Nitrogen in the Leguminous Crops.—The third division of the Table (VI.) gives the results relating to this point.

Referring first to the amounts of nitrogen in the total bean crops (corn and straw together), it is seen that, under each of the three conditions as to manuring, there was from twice to twice and a half as much in the rotation as in the continuously grown beans. The details further show that the advantage was proportionally greater in the corn than in the straw.

It is next to be observed that the amounts of nitrogen taken up by the rotation beans were—without manure about 36 lb. per acre per annum, and with superphosphate between 40 and 50 lb.; whilst with the mixed manure, containing nitrogen, there were in one case 63·6 lb., and in the other 70·2 lb. In fact, both without manure and with superphosphate, the amounts taken up in the beans were much greater than in either the preceding roots or the preceding barley. With the mixed manure supplying nitrogen, they were also much more than in the preceding barley, but less than in the root-crops, to which the mixed manure had been directly applied.

The point of greatest interest in the results is, however, that under each condition as to manuring, the clover took up very much more nitrogen than the beans, and very much more than either of the other crops of the rotation under parallel conditions. Thus, even without manure, the average amount of nitrogen in the two crops of clover was—in one case 55 lb. and in the other 47 lb.; with superphosphate it was 124·5 and 144·6 lb.; and with the mixed manure, containing both potash and nitrogen, in the one case 167 lb. and in the other 168·4 lb. Or, taking the average amount of nitrogen in the six bean and two clover crops, there were—without manure 41·5 and 38·9 lb.; with superphosphate 61·5 and 72·9 lb.; and with the mixed manure 89·5 and 94·7 lb. It is, indeed, to the occasional growth of clover, that the very large average

amounts of nitrogen removed in the leguminous crops of the rotation are to be attributed; and it is these amounts that have to be taken into consideration in comparing the effects on the yield of the other crops of the rotation, and of the rotation as a whole, on the one hand of growing a leguminous crop, and on the other of fallowing, which of course neither yields nor removes nitrogen—unless by loss in drainage.

Further, the figures show that there was generally three or even more times as much of the total nitrogen of the bean crops accumulated in the corn as remained in the straw. Lastly, not only does the leguminous crop of the rotation yield the most nitrogen, but, unless in the case of some of the corn of the beans, the whole of it is supposed to be retained on the farm; and there is, in addition, more or less, and sometimes a considerable amount, of nitrogenous crop-residue left within the soil for succeeding crops.

The Nitrogen in the Wheat Crops.—The results on this head are recorded in the bottom division of Table VI.

Referring first to the amounts of nitrogen in the total produce (grain and straw together), it is seen that, both without manure and with superphosphate alone, that is with the greatest exhaustion, especially of nitrogen, there was generally about, or even more than, twice as much in the rotation as in the continuous crops. With the full manure, both mineral and nitrogenous, applied for the rotation crops only at the beginning of the course, but for the continuous ones each year for the wheat crop to be grown, the relative deficiency in the continuous crops was, however, very much less. Thus, the figures show that the average amounts of nitrogen in the total wheat crops were—without manure nearly 35 lb. per acre per annum in the rotation crops, and only 17 lb. in the continuous ones; with the superphosphate alone nearly 40 lb. under rotation, but in the continuous crops not 20 lb.; and lastly, with the full manure there was an average of more than 42 lb. in the rotation crops, and of 34 lb. in those grown continuously. There is direct evidence, therefore, that there was, under all conditions, more nitrogen available to the crops grown in rotation, than to those growing year after year on the same land; and the advantage is relatively much the greater where no nitrogen had been supplied in manure. The beneficial effect of the interpolation of other crops with the cereals is, therefore, very obvious.

In the case of the second crop of the course—the barley—it was shown that without manure the increased produce in rotation was due to scarcely any roots having been grown, so

that the land was practically fallowed for the barley; and now in the case of the fourth crop—the wheat—there was the preparation either of the growth of a leguminous crop leaving a highly nitrogenous residue, or of fallowing. Then with superphosphate alone, the produce of barley, and the yield of nitrogen in it, were less than without manure where the turnips had been removed, but more where they had not, and where, therefore, there was an available nitrogenous residue from the roots; and now in the wheat, the effects on the available supply of nitrogen, on the one hand of the growth and removal of a leguminous crop, and on the other of actual fallow, are observable. Lastly, with the mixed manure the influence of the direct supply of nitrogen for the first crop of the course is obvious. But, as the amounts of nitrogen taken up were not very much more than where none had been supplied, it is evident that in both cases much must have been due to the influence of the preceding leguminous crop or fallow.

Upon the whole there can be no question that, so far as nitrogen is concerned, the supply within the soil in a condition of combination and of distribution available to the wheat is increased, both by fallow, and by the growth of a leguminous crop, especially of clover; and, further, that such accumulation of available nitrogen by fallow, and of nitrogenous crop-residue by the growth of leguminous crops, is the greater when the soil and subsoil are not abnormally exhausted of organic nitrogen.

Lastly, it is to be observed that, under all conditions of manuring, or other treatment, there was, both in the rotation and in the continuous wheat crops, more than twice, and in some cases considerably more than twice, as much of the total nitrogen of the produce stored up in the grain as in the straw. Hence, in the sale of the grain, and the retention of the straw for home use, by far the greater part of the nitrogen of the crop is exported from the farm.

The Amounts of Total Mineral Matter (Ash) in the Rotation, and in the Continuous Crops.

The results are given in Table VII. for each of the four descriptions of crop, in exactly the same form as those for the total dry matter and the nitrogen, in Tables V. and VI. respectively.

The record is deserving of careful study, as showing the very various, and sometimes very large, amounts of mineral or ash-constituents taken up from the soil, and stored up in the different crops, or parts of the crops. But it must suffice here to

TABLE VII.—*Experiments on the Rotation of—Roots, Barley, Clover (or Beans), or Fallow, and Wheat; in Agdell Field, Rothamsted. 8 courses, 32 years, 1852–1883.*

AVERAGE AMOUNTS OF *MINERAL MATTER (ASH)* PER ACRE PER ANNUM IN THE ROTATION CROPS, COMPARED WITH THOSE IN THE CROPS GROWN CONTINUOUSLY.

		Unmanured				Superphosphate				Mixed mineral and nitrogenous manure			
		Roots carted		Roots fed		Roots carted		Roots fed		Roots carted		Roots fed	
		Fallow	Beans or clover	Fallow	Beans or clover	Fallow	Beans or clover	Fallow	Beans or clover	Fallow	Beans or clover	Fallow	Beans or clover
		lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.
SWEDISH TURNIPS.													
Roots	Rotation	15·7	9·5	13·8	8·8	74·1	71·3	82·5	81·9	167·8	171·2	182·4	172·3
	Continuous[1]	10·9	10·9	10·9	10·9	40·0	40·0	40·0	40·0	100·3	100·3	100·3	100·3
	Rotn. + or − cont.	4·8	−1·4	2·9	−2·1	34·1	31·3	42·5	41·9	67·5	70·9	82·1	72·0
Leaves	Rotation	6·7	6·0	6·6	5·9	17·9	20·4	19·2	22·9	35·2	41·9	40·1	41·6
	Continuous[1]	5·9	5·9	5·9	5·9	16·4	16·4	16·4	16·4	40·5	40·5	40·5	40·5
	Rotn. + or − cont.	0·8	0·1	0·7	0·0	1·5	4·0	2·8	6·5	−5·3	1·4	−0·4	1·1
Total	Rotation	22·4	15·5	20·4	[2]14·7	92·0	91·7	101·7	104·8	203·0	213·1	222·5	213·9
	Continuous[1]	16·8	16·8	16·8	16·8	56·4	56·4	56·4	56·4	140·8	140·8	140·8	140·8
	Rotn. + or − cont.	5·6	−1·3	3·6	−2·1	35·6	35·3	45·3	48·4	62·2	72·3	81·7	73·1
BARLEY.													
Grain	Rotation	34·8	35·9	34·2	30·7	34·9	33·8	44·1	45·9	50·7	51·5	58·1	57·7
	Continuous	21·5	21·5	21·5	21·5	28·4	28·4	28·4	28·4	58·8	58·8	58·8	58·8
	Rotn. + or − cont.	13·3	14·4	12·7	9·2	6·5	5·4	15·7	17·5	−8·1	−7·3	−0·7	−1·1
Straw	Rotation	81·3	87·5	79·2	76·1	75·6	77·7	96·9	99·8	113·5	116·8	145·6	144·9
	Continuous	47·3	47·3	47·3	47·3	55·6	55·6	55·6	55·6	130·6	130·6	130·6	130·6
	Rotn. + or − cont.	34·0	40·2	31·9	28·8	20·0	22·1	41·3	44·2	−17·1	−13·8	15·0	14·3
Total	Rotation	116·1	123·4	113·4	[2]106·8	110·5	111·5	141·0	145·7	164·2	168·3	203·7	202·6
	Continuous	68·8	68·8	68·8	68·8	84·0	84·0	84·0	84·0	189·4	189·4	189·4	189·4
	Rotn. + or − cont.	47·3	54·6	44·6	38·0	26·5	27·5	57·0	61·7	−25·2	−21·1	14·3	13·2
BEANS (6 COURSES), CLOVER (2 COURSES), OR FALLOW.													
Corn	Rotation		18·5		18·4		20·2		24·1		35·8		40·7
	Continuous		7·6		7·6		9·4		9·4		21·1		21·1
	Rotn. + or − cont.		10·9		10·8		10·8		14·7		14·7		19·6
Straw	Rotation		53·1		53·3		65·8		72·5		87·7		90·8
	Continuous		28·5		28·5		35·1		35·1		54·2		54·2
	Rotn. + or − cont.		24·6		24·8		30·7		37·4		33·5		36·6
Total	Rotation		71·6		71·7		86·0		96·6		123·5		131·5
	Continuous		36·1		36·1		44·5		44·5		75·3		75·3
	Rotn. + or − cont.		35·5		35·6		41·5		52·1		48·2		56·2
Clover	Rotation		198·3		[2]172·6		421·3		487·5		569·8		612·5
	Continuous		?		?		?		?		?		?
Average of 8 courses, Beans and Clover			103·3		[2]96·9		169·8		194·3		235·1		251·7
WHEAT.													
Grain	Rotation	26·3	24·6	25·6	22·1	29·6	29·1	30·0	31·1	30·6	33·3	29·5	33·2
	Continuous	13·6	13·6	13·6	13·6	16·3	16·3	16·3	16·3	25·0	25·0	25·0	25·0
	Rotn. + or − cont.	12·7	11·0	12·0	8·5	13·3	12·8	13·7	14·8	5·6	8·3	4·5	8·2
Straw	Rotation	167·9	157·9	160·9	143·5	181·4	172·4	182·5	182·0	187·9	198·9	190·7	196·7
	Continuous	74·4	74·4	74·4	74·4	89·3	89·3	89·3	89·3	136·7	136·7	136·7	136·7
	Rotn. + or − cont.	93·5	83·5	86·5	69·1	92·1	83·1	93·2	92·7	51·2	62·2	54·0	60·0
Total	Rotation	194·2	182·5	186·5	[2]165·6	211·0	201·5	212·5	213·1	218·5	232·2	220·2	229·9
	Continuous	88·0	88·0	88·0	88·0	105·6	105·6	105·6	105·6	161·7	161·7	161·7	161·7
	Rotn. + or − cont.	106·2	94·5	98·5	77·6	105·4	95·9	106·9	107·5	56·8	70·5	58·5	68·2

[1] Average per acre, 19 years, 1849–52 and 1856–70.

[2] Probably crop too low owing to a dell.

direct attention to some of the points of chief interest brought to view, on the consideration of the amount, and of the distribution, of some of the more important individual mineral constituents in the respective crops; and for the purposes of such an illustration reference will chiefly be made to the amounts of phosphoric acid, and of potash, but in some cases to that of lime also, in the crops.

The Amounts of Phosphoric Acid in the Rotation, and in the Continuous Crops.

Table VIII. records the results relating to the amounts of phosphoric acid in the different crops or parts of crops.

The Phosphoric Acid in the Root-crops.—The figures show that, without manure, the rotation turnip crops took up an extremely small amount of phosphoric acid, reaching in only one case to an average of 1½ lb. per acre per annum. By superphosphate alone the amount was increased to an average of about 10 lb.; and although this increase only represents about one-tenth of the phosphoric acid applied in manure it is very important, as it is directly connected with the greatly increased development of fibrous feeding root within the soil, which is a special effect of phosphatic manures when applied to turnips; and it is by virtue of this development that these crops so markedly exhaust the available nitrogen within the soil, and especially the surface soil. As has been shown, there is abundant evidence that the increased amount of nitrogen taken up under the influence of phosphates unaccompanied by any supply of nitrogen itself, is at the expense of the stores of the soil; and that it is not due to a capacity to take up either combined or free nitrogen from the atmosphere, by virtue of an increased development of leaf-surface, under the influence of the phosphatic manure.

With the mixed manure, supplying, besides superphosphate, salts of potash, soda, and magnesia, and a liberal amount of nitrogen as well, there was, although the supply of phosphoric acid by manure was exactly the same, now about twice as much of it taken up, as a coincident of the greatly increased growth, due partly to the other mineral constituents at the same time added, but especially to the influence of the increased available supply of nitrogen. Still, only a small proportion of the phosphoric acid applied was taken up, considering the recognised importance of its application for turnips, and its undoubted specific effects on their growth as above described.

Comparing the amounts of phosphoric acid in the rotation

TABLE VIII.—*Experiments on the Rotation of—Roots, Barley, Clover (or Beans), or Fallow, and Wheat; in Agdell Field, Rothamsted.* 8 *courses*, 32 *years*, 1852–1883.

AVERAGE AMOUNTS OF *PHOSPHORIC ACID* PER ACRE PER ANNUM IN THE ROTATION CROPS, COMPARED WITH THOSE IN THE CROPS GROWN CONTINUOUSLY.

		Unmanured				Superphosphate				Mixed mineral and nitrogenous manure			
		Roots carted		Roots fed		Roots carted		Roots fed		Roots carted		Roots fed	
		Fallow	Beans or clover	Fallow	Beans or clover	Fallow	Beans or clover	Fallow	Beans or clover	Fallow	Beans or clover	Fallow	Beans or clover
		SWEDISH TURNIPS.											
		lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.
Roots	Rotation	1·26	0·77	1·11	0·71	7·91	7·68	8·83	8·78	16·67	17·02	18·14	17·12
	Continuous[1]	0·88	0·88	0·88	0·88	4·14	4·14	4·14	4·14	9·91	9·91	9·91	9·91
	Rotn. + or − cont.	0·38	−0·11	0·23	−0·17	3·77	3·54	4·69	4·64	6·76	7·11	8·23	7·21
Leaves	Rotation	0·29	0·25	0·28	0·25	1·27	1·44	1·36	1·62	2·79	3·17	3·04	3·16
	Continuous[1]	0·25	0·25	0·25	0·25	1·16	1·16	1·16	1·16	3·07	3·07	3·07	3·07
	Rotn. + or − cont.	0·04	0·00	0·03	0·00	0·11	0·28	0·20	0·46	−0·28	0·10	−0·03	0·09
Total	Rotation	1·55	1·02	1·39	[2]0·96	9·18	9·12	10·19	10·40	19·46	20·19	21·18	20·28
	Continuous[1]	1·13	1·13	1·13	1·13	5·30	5·30	5·30	5·30	12·98	12·98	12·98	12·98
	Rotn. + or − cont.	0·42	−0·11	0·26	−0·17	3·88	3·82	4·89	5·10	6·48	7·21	8·20	7·30
		BARLEY.											
Grain	Rotation	11·24	11·59	11·02	9·89	12·29	11·91	15·52	16·16	18·34	18·63	21·04	20·30
	Continuous	6·95	6·95	6·95	6·95	10·00	10·00	10·00	10·00	21·31	21·31	21·31	21·31
	Rotn. + or − cont.	4·29	4·64	4·07	2·94	2·29	1·91	5·52	6·16	−2·97	−2·68	−0·27	−0·41
Straw	Rotation	1·87	2·03	1·82	1·74	1·80	1·85	2·32	2·38	2·87	2·96	3·68	3·53
	Continuous	1·10	1·10	1·10	1·10	1·33	1·33	1·33	1·33	3·30	3·30	3·30	3·30
	Rotn. + or − cont.	0·77	0·93	0·72	0·64	0·47	0·52	0·99	1·05	−0·43	−0·34	0·38	0·23
Total	Rotation	13·11	13·62	12·84	[2]11·63	14·09	13·76	17·84	18·54	21·21	21·59	24·72	24·43
	Continuous	8·05	8·05	8·05	8·05	11·33	11·33	11·33	11·33	24·61	24·61	24·61	24·61
	Rotn. + or − cont.	5·06	5·57	4·79	3·58	2·76	2·43	6·51	7·21	−3·40	−3·02	0·11	−0·18
		BEANS (6 COURSES), CLOVER (2 COURSES), OR FALLOW.											
Corn	Rotation		5·15		5·14		6·81		8·18		11·49		13·05
	Continuous		2·11		2·11		3·16		3·16		6·75		6·75
	Rotn. + or − cont.		3·04		3·03		3·65		5·02		4·74		6·30
Straw	Rotation		1·17		1·17		1·78		1·97		1·99		2·06
	Continuous		0·63		0·63		0·95		0·95		1·24		1·24
	Rotn. + or − cont.		0·54		0·54		0·83		1·02		0·75		0·82
Total	Rotation		6·32		6·31		8·59		10·15		13·48		15·11
	Continuous		2·74		2·74		4·11		4·11		7·99		7·99
	Rotn. + or − cont.		3·58		3·57		4·48		6·04		5·49		7·12
Clover	Rotation		8·04		[2]6·96		20·30		22·99		31·69		34·29
	Continuous		?		?		?		?		?		?
Average of 8 courses, beans and clover			6·75		[2]6·48		11·52		13·36		18·03		19·90
		WHEAT.											
Grain	Rotation	12·53	11·18	12·19	10·50	14·48	14·23	14·68	15·25	15·12	16·50	14·58	16·43
	Continuous	6·45	6·45	6·45	6·45	7·99	7·99	7·99	7·99	12·40	12·40	12·40	12·40
	Rotn. + or − cont.	6·08	4·73	5·74	4·05	6·49	6·24	6·69	7·26	2·72	4·10	2·18	4·03
Straw	Rotation	2·87	2·73	2·76	2·48	3·87	3·75	3·84	3·95	4·94	5·46	5·00	5·31
	Continuous	1·27	1·27	1·27	1·27	1·88	1·88	1·88	1·88	3·62	3·62	3·62	3·62
	Rotn. + or − cont.	1·60	1·46	1·49	1·21	1·99	1·87	1·96	2·07	1·32	1·84	1·38	1·69
Total	Rotation	15·40	13·91	14·95	[2]12·98	18·35	17·98	18·52	19·20	20·06	21·96	19·58	21·74
	Continuous	7·72	7·72	7·72	7·72	9·87	9·87	9·87	9·87	16·02	16·02	16·02	16·02
	Rotn. + or − cont.	7·68	6·19	7·23	5·26	8·48	8·11	8·65	9·33	4·04	5·94	3·56	5·72

[1] Calculated on average produce of 19 years, 1849–52 and 1856–70. [2] Probably crop too low owing to a dell.

crops with those in the continuous ones, the equally small, or even smaller, amount taken up without manure by the latter, is further confirmation of the incapability of this assumed restorative crop to yield any practical amount of produce without adequate soil supplies. With superphosphate alone, as also with the mixed manure, the continuous crops took up little more than half as much phosphoric acid as the rotation ones under the assumed fairly parallel conditions as to manuring. The deficiency is, however, obviously not due to any deficiency of supply within the soil, but is only a coincident of the less total growth, attributable to a great extent, as has been explained, to the unfavourable mechanical condition of the soil induced by the continuous growth of the crop.

Lastly, in regard to the phosphoric acid in the turnip crops, it is to be observed that in all cases much more was accumulated in the edible roots than in the leaves which remain only for manure again; indeed, in the case of the most normal crops, those grown in rotation with the full mixed manure, there was five or six times as much accumulated in the roots as in the leaves.

The Phosphoric Acid in the Barley Crops.—Looking first to the amounts in the total produce, grain and straw together, and to the portions of the rotation plots from which the previous root-crops had been removed, it is seen that, without manure, rather more than 13 lb. of phosphoric acid was, on the average, annually removed in the barley crops; and where superphosphate had previously been applied for the roots, the succeeding barley took up only about 14 lb., that is scarcely any more than without the supply of it; but where the mixed manure, including nitrogen, had been applied for the roots, there was about one-and-a-half time as much, or rather over 21 lb. of phosphoric acid in the succeeding barley crops. Then, where the root-crops had not been removed from the land, the amounts of phosphoric acid in the succeeding barley crops were, without manure, about 12 lb. per acre, with superphosphate about 18 lb., and with the mixed manure nearly 25 lb. In the case of the phosphoric acid, therefore, as in that of the nitrogen, the influence of the manuring, and other treatment, of the preceding crop of the course, is clearly reflected in the amounts taken up in the succeeding barley.

Comparing the amounts of phosphoric acid in the rotation barley crops with those in the continuously grown ones, it is seen that, both without manure and with superphosphate, the rotation crops took up considerably the most phosphoric acid; and this was the case notwithstanding that the continuously

grown crops were annually manured with superphosphate, whilst for those grown in rotation the application had only been for the preceding crop—the turnips. The less assimilation in the case of the continuous crops was doubtless due to the diminished total growth, which in its turn was due to the greater exhaustion of the available nitrogen of the soil with the annual growth. Consistently with this view, where the mixed manure supplying an abundance of nitrogen was applied, and the crops, both rotation and continuous, were pretty full averages for the particular soil and the seasons of growth, the amounts of phosphoric acid in the rotation crops where the roots had not been removed were almost identical with those in the continuous crops. Where, however, the rotation roots had been removed, carrying off therefore the whole of the nitrogen that had been taken up, the succeeding barley crops were accordingly not full for the seasons of their growth, and the amounts of phosphoric acid in them were less than in the continuously grown crops.

The figures relating to both the rotation and the continuous barley further show, that about six-sevenths of the total phosphoric acid of the crops is accumulated in the grain which is supposed to be sold off the farm. There was, indeed, even a somewhat higher proportion where phosphoric acid was supplied in the manure. Lastly, as in the cases of the total produce, the dry matter, and the nitrogen, there is much less difference between the amounts of phosphoric acid taken up under the three different conditions as to manuring than in the case of the turnips. That is, the assumed restorative crop is much more dependent on direct manuring to yield any crop at all than is the cereal crop, which is assumed to be benefited by the interpolation of it.

The Phosphoric Acid in the Leguminous Crops.—Referring to the third division of Table VIII., it is seen that the amounts of phosphoric acid in the total produce of beans, corn, and straw together, was more where superphosphate was supplied than without manure, and more still under the influence of the mixed manure containing, besides superphosphate, salts of potash, soda, and magnesia, and nitrogen also. But, under all three conditions as to manuring, the continuously grown crops take up much less than those grown in rotation. Whether, however, grown in rotation or continuously, three, four, or more times as much of the phosphoric acid is finally accumulated in the corn as remains in the straw. In reference to all the results with beans, however, it is to be borne in mind that under none of the conditions were good crops obtained.

The clover took up, without manure, little more phosphoric acid than the rotation beans; but, with superphosphate, the clover took up more than twice as much as the beans; and with the mixed manure it took up more still, and also more than twice as much as the beans grown under the same conditions.

Taking the average of the six crops of beans and two crops of clover grown in the eight courses, there was, both without manure and with superphosphate, much less phosphoric acid taken up than in either the preceding barley or the succeeding wheat; and even with the mixed manure, which gave the most normal crops, the average amount of phosphoric acid taken up in the beans and clover was less than in either of the two cereals under the same conditions.

The Phosphoric Acid in the Wheat Crops.—The bottom division of Table VIII. shows that the rotation wheat, as did the rotation barley, took up very much more phosphoric acid without manure than did either of the so-called fallow crops —the turnips or the leguminous crops. With superphosphate, again, both the wheat and barley took up more than either the turnips or the average of the leguminous crops. With the full mixed manure, however, when each of the four descriptions of crop grew more normally, the amount of phosphoric acid taken up was more nearly uniform in the four cases; the barley, however, then yielding more than the wheat, more than the turnips, more than the average of the leguminous crops, but all considerably less than the average of the two years of clover.

Comparing the amounts of phosphoric acid in the total produce of the rotation, with those in the continuously grown wheat, it is seen that there is, without manure, only about half as much taken up in the continuous as in the rotation crops; with superphosphate, again, only about half as much in the continuous as in the rotation; but with the more normal growth, when the full mixed manure was annually applied to the continuously grown crops, there was, with the fuller produce, proportionally much more phosphoric acid taken up—indeed, on the average, about three-fourths as much in the continuous as in the rotation crops.

Lastly the figures show, that by far the larger proportion of the total phosphoric acid in the wheat crops is stored up in the grain, which is assumed to be sold off the farm. Thus, without manure more than four-fifths, and with superphosphate nearly four-fifths, of the total phosphoric acid of the crops was in the grain. With the mixed manure, however, with rather larger total amounts taken up than with superphosphate alone, there

was comparatively little more stored up in the grain, the excess for the most part remaining in the straw. The larger amount of total phosphoric acid taken up with the mixed manure than with superphosphate, the amount supplied by manure being the same in the two cases, is to be attributed to the coincident supply of other constituents in the mixed manure, inducing greater luxuriance, and with it greater activity of collection.

The Amounts of Potash in the Rotation, and in the Continuous Crops.

The results relating to the amount and distribution of potash in the rotation and in the continuous crops are recorded in Table IX.

The Potash in the Root-crops.—Before referring to the details on this point, attention should be recalled to the facts fully illustrated in other papers—that root-crops are essentially sugar crops; that the very characteristic effect which nitrogenous manures exert on their increased growth is mainly represented by a greatly increased production of the non-nitrogenous substance—sugar; that, however the action is to be explained, it is certain that the presence of potash is an important condition of the formation in plants of carbohydrates generally; and that, in the case of root-crops, the production of the carbohydrate—sugar—is greatly dependent on a liberal available supply of potash.

Referring to the upper division of the Table, and for the purpose of the first illustrations to the rotation results, it is seen that, without manure and very abnormally small crops, there were only three, four, or five times as much potash in the roots as in the leaves; with superphosphate, on the other hand, and greatly increased root development, there were eight or nine times as much potash in the roots as in the leaves; and with the mixed manure (including potash), there were, with the further greatly increased actual amount of roots and of potash in them, seven or eight times as much in the roots as in the leaves. That is, there was the greatest accumulation of potash with the greatest accumulation of sugar.

Looking to the actual amounts of potash in the total produce, roots and leaves together, of the rotation crops, it is seen that, without manure, there was only from 4 to 6 lb. of potash per acre per annum; but with superphosphate, without potash supply, from 25 to 28 lb. That is, without any supply by manure the plants were able to gather about 20 lb. more potash per acre per annum from the soil itself, by virtue of the

TABLE IX.—*Experiments on the Rotation of—Roots, Barley, Clover (or Beans), or Fallow, and Wheat; in Agdell Field, Rothamsted.* 8 *courses*, 32 *years*, 1852–1883.

AVERAGE AMOUNTS OF *POTASH* PER ACRE PER ANNUM IN THE ROTATION CROPS, COMPARED WITH THOSE IN THE CROPS GROWN CONTINUOUSLY.

		Unmanured				Superphosphate				Mixed mineral and nitrogenous manure			
		Roots carted		Roots fed		Roots carted		Roots fed		Roots carted		Roots fed	
		Fallow	Beans or clover	Fallow	Beans or clover	Fallow	Beans or clover	Fallow	Beans or clover	Fallow	Beans or clover	Fallow	Beans or clover
		SWEDISH TURNIPS.											
		lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.
Roots	Rotation	5·00	3·04	4·40	2·82	22·49	21·67	25·05	24·86	66·62	67·99	72·48	68·53
	Continuous[1]	3·48	3·48	3·48	3·48	12·08	12·08	12·08	12·08	39·51	39·51	39·51	39·51
	Rotn. + or − cont.	1·52	−0·44	0·92	−0·66	10·41	9·59	12·97	12·78	27·11	28·48	32·97	29·02
Leaves	Rotation	1·07	0·95	1·04	0·93	2·60	2·96	2·77	3·31	8·66	10·32	9·89	10·25
	Continuous[1]	0·94	0·94	0·94	0·94	2·38	2·38	2·38	2·38	9·98	9·98	9·98	9·98
	Rotn. + or − cont.	0·13	0·01	0·10	−0·01	0·22	0·58	0·39	0·93	−1·32	0·34	−0·09	0·27
Total	Rotation	6·07	3·99	5·44	[2]3·75	25·09	24·63	27·82	28·17	75·28	78·31	82·37	78·78
	Continuous[1]	4·42	4·42	4·42	4·42	14·46	14·46	14·46	14·46	49·49	49·49	49·49	49·49
	Rotn. + or − cont.	1·65	−0·43	1·02	−0·67	10·63	10·17	13·36	13·71	25·79	28·82	32·88	29·29
		BARLEY.											
Grain	Rotation	8·13	8·38	7·97	7·15	8·09	7·85	10·23	10·65	12·33	12·52	14·14	14·04
	Continuous	5·03	5·03	5·03	5·03	6·59	6·59	6·59	6·59	14·32	14·32	14·32	14·32
	Rotn. + or − cont.	3·10	3·35	2·94	2·12	1·50	1·26	3·64	4·06	−1·99	−1·80	−0·18	−0·28
Straw	Rotation	10·83	11·81	10·52	10·09	9·32	9·50	12·10	12·54	18·41	18·97	23·48	22·31
	Continuous	6·45	6·45	6·45	6·45	7·03	7·03	7·03	7·03	21·00	21·00	21·00	21·00
	Rotn. + or − cont.	4·38	5·36	4·07	3·64	2·29	2·47	5·07	5·51	−2·59	−2·03	2·48	1·31
Total	Rotation	18·96	20·19	18·49	[2]17·24	17·41	17·35	22·33	23·19	30·74	31·49	37·62	37·35
	Continuous	11·48	11·48	11·48	11·48	13·62	13·62	13·62	13·62	35·32	35·32	35·32	35·32
	Rotn. + or − cont.	7·48	8·71	7·01	5·76	3·79	3·73	8·71	9·57	−4·58	−3·83	2·30	2·03
		BEANS (6 COURSES), CLOVER (2 COURSES), OR FALLOW.											
Corn	Rotation		7·26		7·23		7·35		8·79		15·20		17·25
	Continuous		2·98		2·98		3·46		3·46		8·94		8·94
	Rotn. + or − cont.		4·28		4·25		3·89		5·33		6·26		8·31
Straw	Rotation		2·87		2·87		3·47		4·01		6·96		7·21
	Continuous		1·54		1·54		1·82		1·82		4·33		4·33
	Rotn. + or − cont.		1·33		1·33		1·65		2·19		2·63		2·88
Total	Rotation		10·13		10·10		10·82		12·80		22·16		24·46
	Continuous		4·52		4·52		5·28		5·28		13·27		13·27
	Rotn. + or − cont.		5·61		5·58		5·54		7·52		8·89		11·19
Clover	Rotation		34·18		[2]29·67		57·63		65·48		123·12		133·62
	Continuous		?		?		?		?		?		?
Average of 8 courses, beans and clover			16·14		[2]14·99		22·52		25·96		47·40		51·50
		WHEAT.											
Grain	Rotation	8·65	8·08	8·42	7·26	9·55	9·39	9·69	10·06	9·90	10·82	9·55	10·78
	Continuous	4·45	4·45	4·45	4·45	5·27	5·27	5·27	5·27	8·12	8·12	8·12	8·12
	Rotn. + or − cont.	4·20	3·63	3·97	2·81	4·28	4·12	4·42	4·79	1·78	2·70	1·43	2·66
Straw	Rotation	19·12	17·94	18·30	16·31	20·25	19·14	20·45	20·21	25·85	27·47	26·21	27·12
	Continuous	8·49	8·49	8·49	8·49	10·00	10·00	10·00	10·00	18·81	18·81	18·81	18·81
	Rotn. + or − cont.	10·63	9·45	9·81	7·82	10·25	9·14	10·45	10·21	7·04	8·66	7·40	8·31
Total	Rotation	27·77	26·02	26·72	[2]23·57	29·80	28·53	30·14	30·27	35·75	38·29	35·76	37·90
	Continuous	12·94	12·94	12·94	12·94	15·27	15·27	15·27	15·27	26·93	26·93	26·93	26·93
	Rotn. + or − cont.	14·83	13·08	13·78	10·63	14·53	13·26	14·87	15·00	8·82	11·36	8·83	10·97

[1] Calculated on average produce of 19 years, 1849–52 and 1856–70. [2] Probably crop too low owing to a dell.

greatly increased development of fibrous feeding root under the influence of the phosphatic manure. With the mixed manure, however, containing potash, there was about three times as much of it taken up as with superphosphate alone. But, with the supply of potash there was also a liberal supply of available nitrogen, to which the greatly increased growth is largely to be attributed; and with the increased luxuriance much more potash was of course required if there were to be a correspondingly increased formation of the characteristic non-nitrogenous product of the cultivated root-sugar. Thus, we have—without manure only 4 to 6 lb. of potash taken up, with superphosphate (without potash) from 25 to 28 lb., and with the mixed manure, supplying besides phosphoric acid both nitrogen and potash, nearly 80 lb. of potash per acre per annum in the crops.

Comparing the amounts of potash in the rotation crops with those in the continuously grown ones, it is seen that—without manure, and practically no growth, there was but little difference in the amounts taken up; with superphosphate there was little more than half as much taken up in the continuous as in the rotation crops; whilst with the mixed manure, with full supply of potash, and much larger amounts of it in both the rotation and continuous crops, there was rather less than two-thirds as much in the continuous as in the rotation crops. The deficient amounts in the continuous crops are, however, as in the case of the other constituents, coincidents of the less amounts of produce of the continuous crops; which, as has been pointed out, were, in the case of the superphosphate plot, due partly to the greater exhaustion of available nitrogen of the surface soil with the continuous growth, but partly also to the unfavourable mechanical condition of the soil induced by such growth; and this was probably the chief cause of the deficient produce in the case of the mixed manure crops also.

The Potash in the Barley Crops.—The second division of Table IX. records the results on this point.

In the case of the turnips it was found that much more potash was accumulated in the roots than in the leaves; and this fact was assumed to be connected with the greater amount of the carbohydrate—sugar—in the roots than in the leaves. The results relating to the barley show, however, that there was in every case more, and in some much more, potash in the straw than in the grain. On this point it is to be observed, not only that the root-crop is taken up when still in the vegetative stage, and its contents are still in the condition of reserve or migratory material, whilst in the case of the cereal the crop is ripened, and its constituents are, therefore, more

fixed. Further, whilst in the turnip-crop there was several times as much dry substance in the roots as in the leaves, in the barley there was even more dry organic substance in the straw than in the grain. Again, in both crops, by far the larger proportion of the dry substance consists of carbohydrates—in the one chiefly sugar, and in the other almost exclusively starch and cellulose—the latter making up by far the greater portion of the dry substance of the straw. It is obviously quite consistent that under these circumstances there should be more of the total potash of the barley crop accumulated in the straw than in the grain. It must at the same time be observed that, whilst the potash in the grain is comparatively fixed and bears a fairly uniform relation to the amount of dry substance, the quantity which remains in the straw is subject to great variation in proportion to the dry matter, according to the variation in the supply of it within the soil—a great excess above the amount in other cases being sometimes found in the straw. Indeed, the figures show a considerably greater proportion of the total potash of the crop accumulated in the straw where there was a liberal supply of it in manure.

Referring to the amounts of potash taken up in the rotation barley crops on the different plots, according to the manuring or other treatment, the figures show that there was not much difference between the amounts without manure and with superphosphate alone. There was, however, distinctly more taken up on the portions of the superphosphate plot where the roots had not been removed than where they were; and where, therefore, there was conservation for the succeeding crop. With the mixed manure, however, with its supply of potash as well as of phosphoric acid and nitrogen, the amount of potash in the crops is greatly increased, the increase corresponding closely with the increased amount of produce.

Lastly in regard to the potash, whilst without manure and with superphosphate alone the rotation barley has gathered much more than the continuously grown, with the mixed manure and full supply of all constituents, the amounts of potash taken up were, as were those of nitrogen and phosphoric acid, nearly the same in the rotation and the continuous crops where in rotation the preceding roots had not been removed; but where they had been removed, the amounts of potash in the succeeding barley were less, as were the crops themselves.

The Potash in the Leguminous Crops.—Of all the mineral constituents of the crops, perhaps potash and lime are the most generally recognised as having some distinctive effects when applied as manure for leguminous crops. We have now to refer

to the records relating to the potash in these crops, as given in the third division of Table IX.

The figures show that, in the case of the beans, unlike that of the cereals, there is much more potash in the corn than in the straw; indeed, more than twice as much of the potash of the crops was accumulated in the corn as in the straw; indicating, therefore, a special requirement of it for the formation of the final and most fixed product of the plant—the seed.

Looking to the amounts of potash per acre in the total produce, corn and straw together, of the rotation beans, it is seen that they take up very little more under the influence of the superphosphate than without manure; the quantities averaging about 10 lb. per acre without manure, and scarcely 12 lb. with superphosphate. With the mixed manure, however, directly supplying potash for the previous root-crop, the amounts of it taken up were, in the one case 22·16, and in the other 24·46 lb., or about twice as much as with the superphosphate alone. The influence of the previous supply of potash on the amounts of it taken up in the beans was, in fact, much greater than was that of the supply of phosphoric acid on the amounts of it taken up.

But, as in the case of the phosphoric acid, so also in that of the potash, the continuously grown beans took up only about half as much as those grown in rotation; proportionally more, however, where it had been supplied than where it had not. It will be remembered that, when discussing the amounts of produce of the bean crops, attention was called to the fact that throughout the experiments a really good agricultural crop was scarcely ever obtained; and this of course must be taken into account when considering the amounts of the several constituents of the crops.

Comparing the amounts of potash stored up in the rotation clover with those in the rotation beans, it is seen that, even without manure and with very small produce, the clover, with its greater root-range and longer period of growth, gathered up about three times as much potash as the beans—about 30 lb. against only about 10 lb. in the beans.

With superphosphate alone, whilst the bean crops contained only 10·82 and 12·80 lb. of potash, the clover contained 57·63 and 65·48 lb. That is, under the influence of the phosphatic manure, probably partly on the plant and partly on the soil, the clover had accumulated in the removed crop five or six times as much potash as the beans, from the soil itself; whilst, of the phosphoric acid itself, little more than twice as much was taken up in the clover as in the beans under the influence of the

superphosphate without potash. It would thus appear that the beneficial effects of the phosphatic manure on the clover were largely connected with the increased capability of the plant to take up more potash.

With the mixed manure, supplying a large amount of potash, the amount of it found in the clover crops was, however, much greater still. Both in the beans and in the clover the amount of potash in the crops grown under the influence of the direct supply of it was about twice as much as those grown with superphosphate without potash. But whilst, under the influence of the supply of it, the shorter-lived, more meagrely rooting, and less successfully grown bean crops stored up only 22·16 and 24·46 lb. of potash, the clover crops contained in one case 123·12 lb., and in the other 132·62 lb.

The very much larger proportion of the total potash of the bean crops which is found in the corn than in the straw would seem to indicate its greater importance in connection with the maturing than with the merely vegetative and accumulating tendencies of growth; yet the increased amount of it taken up by the beans coincidently with increased growth, and the much larger amounts of it in the clover with its much greater amounts of growth and produce, and harvested as it is in the unripened condition, are on the other hand indications of a direct connection between potash supply and the luxuriance of growth or vegetative activity of these leguminous crops. Indeed, as already referred to, potash manures are well known to be frequently beneficial to such crops. To these points further reference will be made presently, when calling attention to the amount of lime taken up by leguminous crops.

The Potash in the Wheat Crops.—The results on this point are given in the bottom division of Table IX.

It has been seen that by far the larger proportion, both of the nitrogen and of the phosphoric acid of the wheat crops, was accumulated in the grain. But the figures relating to the potash show that of it there was very much more in the straw than in the grain. There was also much more, but not in so great a degree more, in the straw than in the grain of the other cereal —the barley. It has been pointed out that potash is at any rate essentially connected with the formation of the carbohydrates. Consistently with this it was found that by far the larger proportion of the potash of the turnip crop was in the roots, where was the great accumulation of sugar. Again, of the total potash of the barley crop, the larger proportion was found in the straw where there was the greatest accumulation of carbohydrate—as cellulose; and now, in the wheat, with a larger proportion of

straw to grain, and a proportionally larger amount of the total carbohydrates accumulated in the straw, we have in it a still larger proportion of the total potash of the crop. It is, however, to be borne in mind, as has been pointed out, that the straw of both barley and wheat frequently contains, besides the mineral constituents actually essential for the organic formations and changes, a more or less surplus amount taken up as the result of liberal supply, and retained by the plant.

Although there is doubtless clear foundation in fact for the conclusion that the *rôle* of phosphoric acid is more in connection with the formation and activity of the nitrogenous bodies, and that of the potash with those of the non-nitrogenous compounds, yet it is obvious that in such a view we have only a partial and imperfect explanation of the function of these mineral constituents. Thus, in the case of the beans there was, consistently enough, much more phosphoric acid in the corn than in the straw—that is, the more where there was the more nitrogen; but there was also by far the larger proportion of the potash accumulated in the corn, although the greater part of the dry matter of the crop, and with this of its carbohydrates, was in the straw. Indeed, although the leguminous crops are pre-eminently highly nitrogenous, a liberal supply of potash is essential for their luxuriance; whilst they contain a higher proportion of it in their dry substance than do the cereals, with their higher proportion of carbohydrates.

Reference to the figures shows that the application of superphosphate, without potash, enabled the wheat plant, whether grown in rotation or continuously, to take up an increased, but not a much increased, amount of potash, compared with that in the unmanured crops; and that the direct application of it increased the assimilation of it still further, though the increased amount of it stored up represented only a small proportion of that supplied in the manure.

Without manure, the rotation wheat crops contained an average of about 27 lb. of potash, but the continuously grown ones scarcely 13 lb., or only about half as much. With superphosphate, without potash, the rotation crops gave an average of nearly 30 lb., and the continuously grown ones little more than 15 lb.; or, again, only about half as much. That is, when the growing crops had to rely for their potash exclusively on the stores of the soil itself, the rotation crops took up about twice as much as the continuous. Lastly, with the mixed manure supplying potash, the rotation wheat crops gathered nearly 36 lb. after fallow, but about 38 lb. after the leguminous crops; whilst the continuously grown ones yielded an average of only about

27 lb. That is, although in the case of the rotation wheat crops three other crops had been grown since the application of the manure, they took up more potash than the continuously grown ones for which potash was annually supplied.

So much for the results relating to the amounts of the two important and typical mineral constituents—phosphoric acid and potash—taken up by the different crops when grown, respectively, in rotation and continuously, under different conditions as to manuring, and other treatment. Similar results relating to other mineral constituents of the crops have been got out, and the discussion of some of them brings to view points of considerable interest, but neither time nor space will admit of their consideration here. It must suffice to refer briefly to the amounts of lime taken up by the leguminous crops under different conditions; a point which has an interesting relation to the results as to the potash taken up by those crops, and to the questions which arose in the discussion of them.

The Amounts of Lime in the Rotation, and in the Continuous Leguminous Crops.

The following Table (X.) gives, for the leguminous crops alone, the amounts of lime in the rotation and in the continuous crops, in the same form in which the phosphoric acid and potash have been given for each of the four crops of the rotation.

Very different from what was found to be the case with the potash, it is seen that in the rotation bean-crops a very small proportion of the total amount of lime is accumulated in the corn; ten, twelve, or more times as much being found in the straw. Then, the amounts of lime in the total crops were—without manure between 15 and 16 lb.; with superphosphate, which of course supplied some lime, the quantity was raised to 18·68 and 20·71 lb.; and with the mixed manure, also supplying the same amount of lime in its superphosphate, it was further raised to 26·57 and 27·71 lb. It is further seen, that the continuously grown beans contained—in corn, straw, and total produce—in some cases only about, and in others not much more than, half as much lime as the rotation ones.

It is remarkable, however, that whilst without manure the rotation bean-crops contained only from 15 to 16 lb. of lime, the clover contained 67·8 and 59·1 lb.; with superphosphate the beans gave 18·68 and 20·71 lb., and the clover 158·62 and 184·52 lb., or about eight times as much as the beans; and lastly, with the mixed manure, the bean-crops contained 26·57

and 27·71 lb., and the clover 181·75 and 195·14 lb. of lime, or about seven times as much as the beans.

An increased amount of lime is, therefore, even more directly connected with increased luxuriance and increased production, than is an increased amount of potash taken up. Then, again, the increased amount of potash was apparently more or less directly connected with tendency to maturation or seed-formation; but the lime is found chiefly in the straw of the beans, and to be enormously increased in amount in the clover, which does not ripen, but is cut whilst still in the vegetative condition. The

TABLE X.—*Average amounts of Lime per acre per annum in the Rotation, and in the continuously grown, Leguminous Crops.*

	Unmanured				Superphosphate				Mixed mineral and nitrogenous manure			
	Roots carted		Roots fed		Roots carted		Roots fed		Roots carted		Roots fed	
	Fallow	Beans or clover	Fallow	Beans or clover	Fallow	Beans or clover	Fallow	Beans or clover	Fallow	Beans or clover	Fallow	Beans or clover
BEANS (6 COURSES), CLOVER (2 COURSES), OR FALLOW.												
Corn — Rotation		lb. 1·15		lb. 1·14		lb. 1·10		lb. 1·32		lb. 2·10		lb. 2·38
Corn — Continuous		0·47		0·47		~~0·62~~		0·52		1·24		1·24
Corn — Rotn. + or − cont.		0·68		0·67		0·58		0·80		0·86		1·14
Straw — Rotation		14·61		14·66		17·58		19·39		24·47		25·33
Straw — Continuous		7·85		7·85		9·36		9·36		15·08		15·08
Straw — Rotn. + or − cont.		6·76		6·81		8·22		10·03		9·39		10·25
Total — Rotation		15·76		15·80		18·68		20·71		26·57		27·71
Total — Continuous		8·32		8·32		9·88		9·88		16·32		16·32
Total — Rotn. + or − cont.		7·44		7·48		8·80		10·83		10·25		11·39
Clover — Rotation		67·84		[1]59·10		158·62		184·52		181·75		195·14
Clover — Continuous		?		?		?		?		?		
Average of 8 courses, beans and clover		28·78		[1]26·63		53·67		61·66		65·36		69·57

[1] Probably crop too low owing to a dell.

indication is, therefore, that the lime is, both actually and as compared with the potash, much more directly connected with the accumulative or vegetative, as distinguished from the maturing processes of the plant. Certain it is, at any rate, that a largely increased accumulation of lime is a coincident of increased luxuriance in both crops; and it is especially so in the case of the crop the amount of which depends on the extension of the vegetative stages of development, and the production of a large amount of crude or unripened vegetable substance.

Thus, then, the actual and relative importance of potash and lime in the growth of the highly nitrogenous leguminous crops is clearly illustrated in the acreage amounts given, of potash in the third division of Table IX., and of lime in Table X. But the study of the percentage composition of the ashes of the crops, and especially of both the percentage composition of the ashes, and the amount of the constituents per acre, in the bean plant taken at different stages of its growth, and of somewhat similar results relating to the first, second, and third crops of clover, affords further confirmation of the conclusions which have been drawn from the results already considered. It will be impossible to go into any detail here in regard to these further results, and it must suffice to state very briefly their general indications.

The bean-plant ash analyses showed that, on the average, about 75 per cent., and at the time of pod formation nearly 80 per cent., of the total ash consisted of lime, potash, and carbonic acid. Compared with these results, those relating to the more highly nitrogenous clover, which is not allowed to ripen, but is cut when it reaches the blooming stage, so inducing re-growth and extension of the more specially vegetative stages, show that from about 80 to about 84 per cent. of the total ash consisted of lime, potash, and carbonic acid. But whilst in the ash of the ripened corn-yielding bean-crop there was about one-and-a-half time as much potash as lime, in that of the merely vegetating unripened clover there was twice or even three times as much lime as potash. Further, in the ash of the first and third crops of clover, which would be the most succulent and unripe, the relative excess of lime over potash is much greater than in that of the second crop, which develops at the period of the season when the seed-forming tendency is much the greater. Again, in the clover ashes there was about one-and-a-half time as much carbonic acid as in the ash of the ripened bean plant. It is thus further illustrated that a peculiarity of the composition of these pre-eminently nitrogen-assimilating elements of rotation is, that their ashes consist chiefly of lime, potash, and carbonic acid; that the potash predominates in the ripened and less nitrogen-yielding bean-crop; and that the lime and carbonic acid predominate in the continuously vegetating and much more largely nitrogen-accumulating clover.

Referring to the probable or possible significance of these facts, it is obvious that, so far as the nitrogen of the plant is taken up as nitrate of a fixed base, that base, so far as it does not pass back into the roots, will remain in the above-ground parts of the plant, most probably in combination with an organic

acid, which will be converted into carbonic acid in the incineration, and be found as such in the ash, if not expelled by an excess of fixed acid, or by silica.

In the case of the cereals of the rotation, it is probable that most if not all of their comparatively small amount of nitrogen is taken up as nitrate. Potash is by far the predominating base in the ash of the grain, straw, and total produce; lime is in much less amount, both actually and in equivalency; and magnesia is in less amount still, though it is a characteristic constituent of the grain-ashes. There is practically no carbonic acid in either wheat or barley grain-ash, and but little in the straw-ash; and if there have been organic acid salts formed with the base of the nitrate, the carbonic acid may have been expelled in the incineration, by the excess of fixed acid in the grain-ash, or by silica in the straw-ash.

Taking the produce by the mixed manure as the most normal, the root-crops of the rotation come next in amount of nitrogen assimilated over a given area. Potash and lime are the predominating bases. There is much more potash than lime in the more definite product—the root; but the proportion of lime to potash is much greater in the leaf-ash, as would be expected if the nitrogen had been taken up chiefly as calcium nitrate, and the nitric acid subjected to decomposition in the leaves.

Lastly come the Leguminosæ, with their much higher amounts of nitrogen assimilated. These plants also doubtless derive at any rate much nitrogen from nitrates in the soil and subsoil; and it has been shown that their great assimilation of nitrogen is associated with very large amounts of lime and carbonic acid in their ashes.

Referring to the results with the rotation beans grown by the mixed manure, calculation shows that, taking the total crop, corn and straw together, it contained very much less lime than would be required if the whole of its nitrogen had been taken up as calcium nitrate; so that, either part of the nitrogen must have been taken up as nitrate of some other base, or in some quite different state of combination, or as free nitrogen; or some of the lime must have been eliminated from the above-ground parts of the plant into the roots, and possibly some of it passed from them into the soil. Again, the amount of carbonic acid found in the ashes of the crop for 100 of nitrogen in it. would require about one-and-a-half time as much lime as was found in association with it; indicating the probability that part of the nitrogen taken up as nitric acid was as the nitrate of some other base—potash, and possibly to some extent soda also.

Turning to the results with the rotation clover grown by the mixed manure, calculation shows that in the case of this continuously vegetating, unripened, and much higher nitrogen-yielding crop, there was very much more of both lime and carbonic acid in the ash for 100 of nitrogen assimilated than in the total bean-crop. If, however, the whole of the nitrogen of the clover crops had been taken up as calcium nitrate, it would have required nearly twice as much lime as the amount found, provided the whole of it remained; nor would the amounts of potash and soda found suffice to make up the balance. Again, the amount of carbonic acid found is little more than two-thirds as much as would be required to represent organic acid equivalent to the amount of nitric acid subjected to change. Either, therefore, fixed base, partly in combination with organic acid, must have been eliminated from the above-ground parts of the plant, and passed into the roots, and possibly into the soil, or a good deal of the nitrogen must have been taken up in some other form than as nitrate; possibly in part as organic nitrogen taken up from the soil by the agency of the acid sap; or, in part as free nitrogen, probably brought into combination under the influence of micro-organisms within the nodules found on the roots of leguminous plants, the resulting compound being either directly available as a source of nitrogen to the host, or it may be so only after it has itself suffered change.

However this may be, considering the very characteristic differences in the mineral composition of the different crops of rotation according to the amounts of nitrogen they assimilate, the fact that undoubtedly the highly nitrogenous Leguminosæ do take up at any rate a large proportion of their nitrogen as nitrate, and that the greater the amount of nitrogen assimilated the more is the ash characterised by containing fixed base, and especially lime, in combination with carbonic acid, it seems very probable, if not indeed established, that the office of the lime, and partly that of the other bases also, is that of carriers of nitric acid; which, when transformed, and the nitrogen assimilated, leaves the base as a residue, presumably in combination with organic acid. Further, the power of these plants to assimilate so very much more nitrogen over a given area than the other crops may, at any rate in part, be dependent on their being able, by virtue of the range and character of their roots, to gather up more nitrogen in the form supposed than the plants with which they are alternated. Such a view does not, however, exclude the supposition that some of their nitrogen is derived in other ways, as above referred to.

In connection with the foregoing results of direct experi-

mental investigation into the mineral composition of leguminous crops, it may be observed—that clover at any rate grows more favourably on land that has recently been chalked or limed; that chalking or liming of the mixed herbage of grass land also favours the development of the leguminous herbage; and that the application of gypsum to clover has been found very effective on some lands, especially in America, though it has not proved to be at all generally useful when it has been so applied in this country. Indeed, the direct application of potash as manure is certainly more frequent, and is more generally recognised as effective for leguminous crops, than is that of lime, notwithstanding its obvious importance, and its great influence on the luxuriance of growth of such crops. This may perhaps be partly explained by the fact that, in many, if not in most, soils, the immediately available supply of potash within the root-range of the plant will probably be sooner exhausted than will that of lime.

Summary and General Conclusions.

It remains, in conclusion, very briefly to summarise the facts brought out in this extended inquiry on the subject of rotation, and to endeavour to draw from them an explanation of the benefits arising from the practice of it.

At the commencement it was pointed out, that although many different rotations are adopted, they may for the most part be considered as little more than local adaptations of the system of alternating root-crops and leguminous crops with the cereals. Thus, there are rotations of five, six, seven, or more years. But these variations are, in most cases, only adaptations of the principle to variations of soil, altitude, aspect, climate, markets, and other local conditions; and they consist chiefly in the variation in the description of the root-crop, and perhaps the introduction of potatoes; in growing a different cereal, or it may be more than one cereal consecutively; in the growth of some other leguminous crop than clover; or the intermixture with the clover of grass seeds; and perhaps the extension of the period allotted to this element of the rotation to two or more years.

It is true, also, that, under any specific rotation, there may be deviations from the plan of retaining the whole of the root-crop, the straw of the grain crops, and the leguminous fodder-crops, on the farm, for the production of meat or milk, and, coincidently, for that of manure to be returned to the land. But it is also true that, when under the influence of special local, or

other demand—proximity to towns, easy railway or other communication, and so on—the products which would otherwise be retained on the farm are exported from it, the import of town or other manures is generally an essential condition of such practice. Indeed, this system of free sale very frequently involves full compensation by purchased manures of some kind. In our own country, such deviations from the practice of merely selling grain and meat have been much developed in recent years; and they will doubtless continue to increase under the altered conditions of our agriculture, dependent on very large imports of grain, increasing imports of meat and other products of feeding, and very large imports of cattle-food and other agricultural produce. Already much more attention is being devoted to dairy products, not only on grass farms, but on those that are mainly arable; and there will doubtless be some, but probably by no means so great an extension as some suppose, in the production of other smaller articles required by town populations.

It is further true, though the remark applies in a very limited degree to our own country, that there are other deviations which have more the character of exceptions to the general rule of rotation, such as the introduction of flax, hemp, tobacco, or other so-called *industrial* crops. But, in these cases, as with potatoes, the growth involves special expenditure for manure instead of conservation of it. Indeed, the inducement is the high price of the product, rather than the maintenance, or the improvement, of the condition of the land for future crops.

Still, as such deviations from regular rotation practice as have been referred to, do, as has been said, generally involve more or less, and frequently full, compensation by manure from external sources, we may, in endeavouring to explain the benefits which accrue from the practice of rotation, confine attention, for the purposes of illustration, to what may be called the self-supporting system, and to the simple four-course one which has been selected for investigation at Rothamsted, and from the results relating to which the illustrations which have been brought forward have been drawn.

It will be well first briefly to refer to the evidence relating to some of the more important mineral constituents found in the different crops of the four-course rotation.

Of *phosphoric acid*, the cereal crops take up as much as, or more than, any of the other crops of the rotation, excepting clover; and the greater portion of what they take up is lost to the farm in the saleable product—the grain. The remainder, that in the straw, as well as that in the roots and the legu-

minous crops, is supposed to be retained on the farm, excepting the small amount exported in meat and milk.

Of *potash*, each of the crops takes up very much more than of phosphoric acid. But much less potash than phosphoric acid is exported in the cereal grains, much more being retained in the straw; whilst the other products of the rotation—the roots and the Leguminosæ—which are also supposed to be retained on the farm, contain very much more potash than the cereals, and comparatively little of it is exported in meat and milk. The general result is, that the whole of the crops of rotation take up very much more of potash than of phosphoric acid, whilst probably even less of it is eventually lost to the land.

Of *lime*, very little is taken up by the cereal crops, and by the roots much less than of potash; more by the Leguminosæ than by the other crops, and, by the clover especially, sometimes much more than by all the other crops of the rotation put together. Of the lime of the crops, however, very little goes in the saleable products of the farm under the conditions supposed of a self-supporting rotation. There is, however, frequently a considerable loss of lime in land-drainage.

Although the facts relating to other mineral constituents of the crops are not without significance, reference can be made here to only one other of these constituents—namely, the *silica*.

The interpolated crops of rotation—the Roots and the Leguminosæ—take up scarcely any silica; but the cereals take up a very large amount of it. Indeed, the large amount of silica taken up by these crops when grown under ordinary conditions, is as characteristic a chemical phenomenon of rotation as is the very large amount of lime taken up by clover and other Leguminosæ. Very little silica, however, is lost to the land in the assumed saleable products.

Thus, then, although different, and sometimes very large, amounts of these typical mineral constituents are taken up by the various crops constituting the rotation, there is no material export of any in the saleable products, excepting of phosphoric acid and of potash; and, so far at least as phosphoric acid is concerned, experience has shown that it may be advantageously supplied in purchased manures.

But, although the eventual loss to the land of mineral constituents is, in a self-supporting rotation, comparatively so small, the very fact that the different crops require for their growth, not only very different amounts of individual constituents, but require these to be available within the soil in very different conditions, both of combination and of distribution, points to the conclusion that, in any explanation of the benefits of an alter-

nation of crops, the position, and the *rôle*, of the mineral constituents must not be overlooked; and the less can it be so, when their connection with the very important element—the nitrogen of the crops—is considered.

As to the *nitrogen*:—It has been seen that, although very characteristically benefited by nitrogenous manures, the cereal crops take up and retain much less nitrogen than any of the crops alternated with them. In fact, the root-crops may contain two, or more, times as much nitrogen as either of the cereals, and the leguminous crop, especially the clover, much more than the root-crops. The greater part of the nitrogen of the cereals is, however, sold off the farm; but perhaps not more than 10 or 15 per cent. of that of either the root-crop, or the clover, or other forage leguminous crop, is sold off in animal increase or milk. Thus, most of the nitrogen of the straw of the cereals, and a very large proportion of that of the much more highly nitrogen-yielding crops, returns to the land as manure, for the benefit of future cereals and other crops. Indeed, it is, as a rule, only a comparatively small proportion of the very much increased amount of nitrogen obtained in rotation compared with that in continuous cereal-cropping (chiefly due to the interpolated crops), that is lost to the land in the saleable products.

As to the source of the nitrogen of the so-called 'restorative crops,' it has been shown that certainly in the case of the roots it is not, as has sometimes been assumed, that such plants take up nitrogen from the air by virtue of their extended leaf-surface. Both common experience and direct experiment demonstrate, that they are as dependent as any crop that is grown, on available nitrogen within the soil, which is generally supplied by the direct application of nitrogenous manures—natural or artificial. Under such conditions of supply, however, the root-crops, so to speak gross feeders as they are, and distributing a very large amount of fibrous feeding root within the soil, avail themselves of a much greater quantity of the nitrogen supplied than the cereals would do under similar circumstances; this result being partly due to their period of accumulation and growth extending even months after the period of collection by the ripening cereals has terminated, and at the season when nitrification within the soil is the most active, and the accumulation of nitrates in it is the greatest. Lastly, full supply of both mineral constituents and nitrogen being at command, these crops assimilate a very large amount of carbon from the atmosphere, and produce, besides nitrogenous food-products, a very large amount of the carbohydrate—sugar, as respiratory and fat-forming food for the live-stock of the farm.

Very much the same may be said of maize as grown as a fodder-crop in America, as of roots as grown in rotation in other countries. Thus, there can be no doubt that the maize derives its nitrogen from the soil, collecting some time longer than wheat, and availing itself of the nitrates formed after the collection by the wheat has ceased. But, so far as the product is consumed on the farm, much of its nitrogen is recovered in the manure—the more when the food is used for growing or fattening stock, and the less when for the production of milk.

The still more highly nitrogenous leguminous crops, on the other hand, although not characteristically benefited by nitrogenous manures, nevertheless contribute much more nitrogen to the total produce of the rotation than any of the other crops comprised in it. It is also certain that, at any rate a large proportion of the nitrogen of these crops is obtained from the soil and subsoil; though recent investigations have proved that some of their nitrogen, and sometimes much of it, may be derived indirectly from the free nitrogen of the atmosphere, brought into combination under the influence of micro-organisms within the nodules on the roots of the plants.

It is the leguminous fodder crops, and among them especially clover, which has a much more extended period of growth, and much more extended range of collection within the soil and subsoil, than any of the other crops of the rotation, that yield in their produce the largest amount of nitrogen per acre. Much of this is doubtless taken up as nitrate; yet, the direct application of nitrate of soda has comparatively little beneficial influence on their growth. The nitric acid is probably taken up chiefly as nitrate of lime, but probably as nitrate of potash also, and it is not without significance that the high nitrogen-yielding clover takes up, or at least retains, very little soda. The general result is, then, that although undoubtedly the clover takes up a good deal of its nitrogen as nitrate, this would seem to be derived from accumulations within the soil, which are brought into suitable conditions of combination, and distributed through a wide range of soil and subsoil.

So much then for the benefits of rotation, so far as the requirements, the habits of growth, and the capabilities of gathering and assimilating the various mineral constituents, and the nitrogen, of the different crops, are concerned. It cannot be doubted that the difference in the amounts, in the conditions of combination, and in the distribution within the soil, of the various mineral constituents, is at least an element in the explanation of the benefits of alternation; nor, on the other

hand, can there be any doubt that the facts relating to the amount, and to the sources, of the nitrogen of the different crops, are of still greater significance than are those in regard to the mineral constituents.

But, it is not only the conditions of growth, but the *uses* of the different crops when grown, that have to be taken into account. Thus, the cereals, when grown in rotation, yield more produce for sale in the season of growth than when grown continuously. Again, the crops alternated with them accumulate very much more of mineral constituents and of nitrogen in their produce, than do the cereals themselves; and, by far the greater proportion of those constituents remains in circulation in the manure of the farm, whilst the remainder yields highly valuable products for sale in the forms of meat and milk.

Further, independently of the benefits arising from the difference in the requirements and results of growth of the different crops, of the increased amount of manure available, and of the increased sale of highly valuable animal products, there are other elements of advantage of considerable importance. For example, with a variety of crops, the mechanical operations of the farm, involving horse and hand labour, are better distributed over the year, and are therefore more economically performed. Last, but by no means least, the opportunities which alternate cropping affords for the cleaning of the land from weeds is a prominent element of advantage.

Thus, then, the benefits of rotation are very various; and the explanation of them, though largely dependent on the facts which have been ascertained by scientific investigation, also largely involves considerations connected with the general economy of the farm; and since, as has been seen, so large a proportion of the produce grown is retained on the farm, as stock-food or litter, it is obvious that the benefits cannot be fully appreciated without arriving at some definite idea of the importance to the farmer of the saleable animal products, and of the manure obtained. It is proposed to consider this subject in a future paper.

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THE

DEPRESSION OF CORN PRICES

AND THE

PRODUCTION OF WHEAT

IN SOME OF THE

CHIEF EXPORTING COUNTRIES OF THE WORLD.

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1897.

ON THE DEPRESSION OF CORN PRICES; AND ON THE PRODUCTION OF WHEAT IN SOME OF THE CHIEF EXPORTING COUNTRIES OF THE WORLD.

HAVING communicated a paper on the production of wheat in some of the chief exporting countries of the world to the International Agricultural Congress, held at Budapest in September last, it has been thought that a discussion of the question would be of interest to agricultural readers in our own country, and elsewhere, at the present time. We have, accordingly, as far as possible completed the tabular record, and have carefully reconsidered the subject, having regard to such further information as was available, with a view to publication in this Journal.

In discussing the probabilities of the extension, or the limitation, of the production of wheat throughout the world, it is obviously of interest and importance to consider—what are the circumstances which have led to the enormously increased production in recent times; and what, so far as is known, are the conditions of the chief exporting countries at the present time. In illustration of the subject, we have brought together in the Table on p. 4 a record of the *exports*[1] of wheat from some of the chief wheat-growing countries, both those which have hitherto contributed the greatest supplies, and those which have shown a marked tendency to increase in their production and export in recent years. The quantities are given uniformly for all the countries in quarters of 480 lb.; and it should be further explained that, unless otherwise stated, they relate to *net exports*, that is, exports less imports. The chief exception is in the case of Russia in Europe, for which the record of imports, if any, was not available. We desire here to acknowledge our great obligation to both the Board of Trade and the Board of Agriculture, for kindly, at considerable trouble, affording us facilities for acquiring the information essential for our purpose.

[1] It will be readily understood that it is much more difficult to obtain reliable records of the *exports* from different countries, than of the *imports* into our own country. Thus, for the exports from other countries, dependence has to be placed on the records of the individual countries themselves, which are not always as complete as might be desired, and which are in many cases given only in their own languages, and in weights or measures different from our own.

Net Exports (Exports minus Imports) of Wheat, and of Flour reckoned as Wheat, from the chief Exporting Countries of the World.

(In quarters of 480 lb.)

[*Where figures are given in parenthesis, and with the minus sign, the imports exceeded the exports; and in taking averages of the exports, these amounts are deducted.*]

Years	United States	Canada [1]	British India [2]	Russia in Europe [3]	Austria-Hungary [4]	Roumania [5]	Argentina [6]	Chili [7]	Uruguay
	Years ending June 30	Years ending June 30	Years ending Mar. 31	Years ending Dec. 31	Years ending Dec. 31	Years ending Dec. 31	Years ending Dec. 31	Years ending Dec. 31	Years ending Dec. 31
	Quarters	Quarters	Quarters	Quarters	Quarters	Quarters	Quarters	Quarters	Quarters
1871	6,253,720	(−1,251,572)	57,988	8,805,917	2,013,731	—	149	—	—
1872	4,437,298	(− 91,372)	148,656	7,308,729	(− 20,967)	—	1,392	—	—
1873	6,127,573	194,484	91,165	5,303,713	(−894,548)	—	800	—	—
1874	10,942,679	603,539	408,051	6,237,881	(−787,896)	—	1,797	—	—
1875	8,826,428	153,485	239,600	7,149,524	229,378	—	(− 22,360)	549,052	—
1876	8,909,175	448,635	581,261	6,974,283	445,227	—	(− 19,149)	481,482	—
1877	6,891,855	(− 283,358)	1,290,299	6,840,274	1,794,311	—	(− 1,295)	388,679	57,331
1878	11,115,706	454,750	1,388,666	12,827,303	2,163,926	—	30,232	228,776	54,003
1879	18,229,717	775,558	152,141	10,366,036	1,866,357	2,094,822	128,026	652,857	40,196
1880	22,504,854	835,316	512,750	4,666,427	(−231,524)	1,869,430	(− 78,928)	709,538	(− 9,704)
1881	23,300,600	369,376	1,743,245	6,114,113	252,846	904,290	(− 73,585)	530,782	24,144
1882	15,155,936	612,127	4,603,669	9,510,389	1,883,482	1,850,444	(− 9,150)	688,455	(− 38,438)
1883	18,383,358	849,059	3,279,265	10,367,622	1,715,860	1,817,689	287,822	631,020	9,268
1884	13,979,928	(− 232,141)	4,871,849	8,457,511	888,038	1,195,074	521,263	461,706	5,477
1885	16,594,001	57,549	3,719,075	11,579,054	1,038,573	1,821,845	407,814	528,868	48,309
1886	11,809,868	530,010	4,954,493	6,590,676	1,774,619	1,400,805	207,311	604,603	85,755
1887	19,243,394	899,376	5,284,229	9,770,640	1,850,690	2,352,212	1,126,417	591,239	68,314
1888	14,934,394	412,109	3,257,519	15,645,729	3,215,153	3,900,329	561,866	446,597	147,125
1889	11,101,603	(− 62,218)	4,184,797	13,274,580	2,293,730	4,436,111	111,755	240,794	(−179,793)
1890	13,715,306	(− 58,152)	3,331,164	12,204,993	1,941,144	4,285,125	1,576,083	146,156	(− 24,863)
1891	13,252,167	386,289	3,444,168	11,926,056	1,306,156	3,091,753	1,860,441	782,322	(− 4,319)
1892	27,970,783	1,271,392	7,163,387	5,415,065	578,624	3,645,669	2,278,740	694,263	(− 5,411)
1893	23,945,008	1,320,891	3,633,726	10,220,161	522,867	3,344,378	4,870,424	853,879	97,209
1894	20,465,585	1,399,722	3,018,342	15,087,241	335,228	3,327,944	7,644,517	533,712	724,447
1895	17,992,471	1,112,273	1,740,588	17,471,801	257,197	4,560,979	4,950,347	360,939	582,324

SUMMARY—AVERAGES.

5-yearly periods									
1871-75	7,317,540	(− 78,287)	189,092	6,961,153	107,960	—	(− 3,644)	(549,052)	—
1876-80	13,530,261	446,180	785,023	8,334,865	1,207,659	(1,982,126)	11,777	492,266	(35,457)
1881-85	17,482,765	331,194	3,643,321	9,205,738	1,155,760	1,517,868	226,833	568,166	9,752
1886-90	14,160,913	345,225	4,202,440	11,497,324	2,215,067	3,274,916	776,686	406,878	19,308
1891-95	20,725,203	1,098,113	3,800,042	12,024,065	600,014	3,594,145	4,320,894	645,023	278,850
25 yrs. 1871-95	14,643,336	428,485	2,523,984	9,604,629	1,057,292	(2,699,935)	1,066,510	(528,844)	(88,493)

[1] 1871-76, the imports, and possibly the exports, of flour, included some rye flour.

[2] 1871 and 1872, gross exports of wheat only; no record of imports of wheat, and no records of flour. 1873-76, no records of flour.

[3] No record of imports available; the figures show gross exports only.

[4] Flour, both exports and imports, recorded as flour *and meal*, which we have reckoned as flour.

[5] For 1886, gross exports of wheat only; there being no record of imports of wheat or flour, or exports of flour.

[6] 1871-74, no record of imports available; figures show exports only.

[7] For 1879, 1893, 1894, and 1895, gross exports of wheat only; there being no record of imports of wheat or flour, or exports of flour.

As to the causes which have led to such greatly increased production of wheat, it may be stated that, in ten out of the twelve years from 1871 to 1882 inclusive, there was less than the average yield of the crop in the United Kingdom; and that, in some of the same years, there was a deficient yield in Western Europe generally. It may be added, that the imports into our own country began considerably to increase after the harvest of 1872, and that they were more than twice as much in the harvest-year, 1882–3, as in that of 1871–2. Further, notwithstanding the comparatively large proportion of average or over average yields since 1882, our own imports have, owing to increased population, and reduced area under the crop in consequence of low prices, maintained a very high level; and over the five years 1891–2 to 1895–6 inclusive, they were considerably higher than in 1882–3. The imports of Western Europe generally have also been considerably higher over the period under review than previously.

It was, in fact, the bad seasons in the United Kingdom, and sometimes also in Western Europe, between 1871 and 1882, but culminating in 1879, that stimulated the greatly increased production for export in other countries.

The United States.

The United States came the soonest and the most rapidly into the market. Thus, according to official returns, the increase in the wheat-growing area in the United States in the five years ending 1877 amounted to rather over 5⅜ million acres; whilst in the next four years, 1878–81, it was rather more than 11⅜ million acres; together making an increase of more than 16¾ million acres over the nine years 1873–81 inclusive. Over the next eleven years, however, 1882–92, there was an increase of not much more than ¾ million acres; the whole increase over the twenty years, 1873–92 inclusive, amounting to about 17⅜ million acres. The highest area recorded was in 1891, namely, 39,916,897 acres. In 1892 it was 38,554,430, or about 1⅓ million less; but in 1893 it was only 34,629,418; in 1894, 34,882,436; in 1895, 34,047,332; and in 1896, 34,619,000 acres. That is, there was an estimated average of about 5⅓ million acres less over the last four years than in 1891, and of about 4 million less than in 1892; part, at least, of the indicated reduction being due to the substitution of other crops.

In accordance with the foregoing facts, reference to the figures in the Table will show, that the exports from the United States began to increase rapidly after 1873, and that, with fluctuations due to season and other circumstances, they have

continued to do so almost up to the present time. In the years ending June 30, 1880 and 1881, the exports were more than twice as great as in the year ending June 30, 1874. The largest exports were, however, in the years ending June 30, 1892 and 1893, after the large areas in 1891 and 1892. But, in the years ending June 30, 1894 and 1895, there was, with reduced area and low prices, reduction in the exports; whilst the returns show, that in the year ending June 30, 1896, they were, though still high, lower than in the preceding year; and the indications are that they will probably be lower still in the current fiscal year.

It is to be borne in mind that the larger proportion of the increased area brought under cultivation in the United States for wheat production and export, as above recorded, consisted of rich prairie land. The question arises, therefore, what are the probabilities of the maintenance, the increase, or the decrease, of this large production for export? Obviously the fact that so much capital has been invested in bringing such large areas under cultivation for the purpose, would point to the conclusion that it is not likely to be abandoned. On the other hand, it is alleged, that the wheat lands in the United States from which such large exports have been derived, are to a great extent already exhausted; and that Europe need not any longer fear their competition in wheat production. Now, it has been seen that more than 16¾ million acres were brought under cultivation in the nine years 1873–81 inclusive, and by far the larger proportion within the last four years of the period; so that much of the land now said to be exhausted has only been from fifteen to twenty years under cultivation. Further, a very large proportion of the newly broken up land having been rich prairie, frequently as rich as, or richer than, good old pasture lands in Europe, and sometimes to a considerable depth, it seems quite impossible that there can be material exhaustion in so short a time. Notwithstanding the inherent richness of the land, however, the average produce of the whole of the wheat area of the United States, including so large a proportion of rich prairie land, is only between 12 and 13 bushels per acre, against more than twice as much, between 27 and 28 bushels, the average produce under ordinary cultivation, of the very much poorer lands of the United Kingdom. Again, the unmanured plot of the comparatively poor soil of the permanent experimental wheat field at Rothamsted, has yielded an average of more than 13 bushels per acre per annum over fifty consecutive years without any manure; that is, more than the average of the whole of the United States, including so much of rich prairie

land; and, so far as is known, about the average of the whole of the wheat lands of the world.

How are these facts to be accounted for? The wheat produced in ordinary agricultural practice on the comparatively poor lands of the United Kingdom is grown in rotation, the land is fairly cultivated, and is kept fairly clean. In the case of the growth of an average of more than 13 bushels per acre for fifty years in succession without manure at Rothamsted, the land has been kept as free from weeds as possible. On the other hand, most of the export lands of the United States are scarcely more than skimmed by the plough, scarcely any labour is bestowed on cleaning, weeds largely rob the fertility, the straw and weeds are to a great extent burnt, and manure is often wasted or destroyed. These are certainly conditions well calculated to reduce fertility rapidly. But, considering the original character of the land in most cases, it is impossible to believe that the large wheat-growing areas of the United States, said to be already exhausted, would not, with good cultivation, yield large crops for many years to come. This result can, however, only be attained by an increased expenditure of both capital and labour. Such, however, is the mortgage and other indebtedness of many of those growing wheat for export, that it is to be expected that the application of more capital will be only limited for some time to come. It is true that, in the case of new settlement, with sparse population, though fertility may be cheap, labour is dear, and hence wasteful modes of production are, for a time at least, almost inevitable.

As population becomes more dense, however, local markets will arise for rotation products, more stock will be kept, the straw and the manure will be utilised, cultivation will be improved, and weeds will lose their ascendency. Nor can there be any doubt that, when such conditions prevail, it will be found that the growth of comparatively small crops of wheat, even with a considerable share of weeds, for fifteen or twenty years on rich prairie lands, has not exhausted their fertility. It is also to be borne in mind that there is yet more, and some of it rich, land to be brought under the plough.

On the other hand, the home consumption of wheat in the United States has increased very largely in recent years. According to published records, it has risen from rather under 200 million Winchester bushels in 1872–73, to an average of nearly 334 million over the ten years from 1882–83 to 1891–92. Notwithstanding this, the exports increased from 52½ million bushels in 1872–73 to an average of 146½ million over the five years from 1877–78 to 1881–82; but they amounted to an

average of rather less than 130 million over the ten years 1882–83 to 1891–92. The maximum amount in any one year was 227½ million in 1891–92; and in 1892–93 it was 192½ million bushels.

It has been estimated, however, that judging from the increase of the population in the past, the central, northern, and western States, from which such large exports of grain are derived, will, before many years have passed, be as densely populated as the eastern States are now, and that then the export of grain will be rapidly diminished. In this calculation, however, the essential difference in the character of the land in the eastern States, and that of the prairie districts of the central, northern, and western States, is not duly taken into account. It is true that both western wheat and western meat are materially reducing the production of them in the eastern States; so that the population of the east as well as of the west will consume more and more of the western produce, leaving the less for export. But, notwithstanding the increased and increasing demand for home consumption, and the allegation, which is now several years old, that the wheat-producing lands are already showing signs of exhaustion, the Table shows, as has already been pointed out, that the exports were higher in the years ending June 1892 and June 1893 than in any other year of the series given; and those for the years ending June 1894 and June 1895 (also June 1896) were, although showing progressive reduction, nevertheless considerably higher than the average.

From the foregoing facts relating to the production of wheat in the United States, we think there can be no doubt that there still exists great inherent capability of production for export; but, that the maintenance of the rate of recent years, and still more, an increase, can probably only be attained by considerably increased expenditure of capital and labour; whilst, considering the financial conditions which have been referred to, the scarcity and cost of labour, and the present low prices of the produce, it seems probable that any change in the direction supposed will be but limited within the near future. Further, in some localities, the cost of freight to the sea-board becomes more or less an impediment to successful competition with countries more favourably circumstanced in this respect.

Canada.

Canada, in its North-west Provinces, comprises large areas adapted for the growth of wheat, a considerable proportion of

which is naturally very fertile; but the population of those Provinces is, though growing, only sparse up to the present time. In Lower Canada, however, there is a considerable population; and the home consumption has necessitated the importation of considerable amounts of both wheat and flour, though less during recent years than previously. The figures given in parenthesis, and with the *minus* sign, in the column in the Table relating to Canada, indicate that in those years the imports overbalanced the exports. In other cases, the records represent the *net exports* (gross exports *minus* imports); and they show, notwithstanding the increasing demand for home consumption with the increasing population, a considerable increase of exports during the last few years. So far as extent of area suitable for wheat production is concerned, there can be no doubt that Canada possesses great inherent capabilities for export; but the amount of land brought under cultivation for the purpose does not increase rapidly. Indeed, as in the United States, both more capital and more labour are required for further development; whilst, under existing conditions, both the cost of freight, and the low prices of grain ruling throughout the world, are adverse to any rapid extension within the near future.

British India.

The exports of wheat from British India are considerably larger than those from Canada, but they bear only a small proportion to those from the United States, or Russia in Europe; or, in recent years, to those from Argentina, as will be seen further on. The figures in the Table show that, as in other cases, the export of wheat from British India began to increase as the deficiency in the United Kingdom and Western Europe developed owing to bad seasons. But it was about fifteen years ago that it showed such a tendency to rapid increase as to lead to the assumption that the exports thence were likely to come into formidable competition with those from other exporting countries. The figures further show, however, that, with the exception of the year ending March 31, 1892, after the failure of the crop in Russia, and the consequent greatly reduced exports therefrom, they have declined considerably in recent years compared with those ending March 31, 1882, 1884, 1886, and 1887. Indeed, in the year ending March 31, 1895, they were very much lower than in any year since that ending March 31, 1881. They were, however, again higher in the year ending March 31, 1896; but, owing to failure of the crop from drought over large areas, British India is at the present time a wheat-importing country.

The conditions of the growth of wheat for export in British India are, in fact, as different as could well be conceived from those of most other exporting countries. As has been seen, the exports from the United States and Canada are mainly derived from large areas of, for the most part, rich virgin soil, which have mostly been broken up for the purpose of wheat production. The same applies in a greater or less degree to large wheat growing areas in other exporting countries. In British India, on the other hand, the crop has been grown for export on poor soil, which has long been under the ordinary cultivation of the country, which has been very much exhausted, and where, with a dense and frequently insufficiently fed population, labour is cheap.

Taking the average of several years, it would seem from published records that wheat was only grown on about, or on little more than, one-tenth of the cultivated area; whilst the proportion of the total produce which was exported, ranged from under 10 to over 20 per cent., and averaged about 15 per cent. It may, in fact, almost be said that the land devoted to the growth of wheat for export, represents an ill-spared margin of that required for the food supplies of the people; as is well illustrated by the result of the failure of the crop at the present time. The produce per acre is very small, though it is admitted that it might be considerably increased if sufficient manure were available, which it is not. It is not to be wondered at, that, under the actually existing conditions, the amounts of the exports should show considerable fluctuations, and that they have, upon the whole, shown signs of diminution in recent years.

It is, it is true, uncertain to what extent the result is due to the local conditions under which the crop is grown, or how far the prevailing low prices in other countries have had an influence. It is indeed alleged, that the extension of irrigation to large tracts of land already under cultivation would greatly increase the production of wheat for export; and further, that there yet remain very large areas of cultivable, but as yet uncultivated, land. Such possible or prospective sources of increased capability of production of wheat for export, however important to bear in mind, could obviously only be very slowly developed, and can hardly be taken into calculation in estimating the probability of increase within the near future. At any rate, considering the circumstances of the growth hitherto, it cannot be said, as in the case of some other large wheat-exporting countries, that there is a great reserve of dormant fertility readily and rapidly available for the increased production for export.

Australasia.

Owing to the passage of produce from one Colony to another, and to defective statistics, it is impracticable to give a reliable estimate of the net exports of the whole collectively for a series of years. Judging, however, from the imports into the United Kingdom from 1871 up to the present time, there was increase over the second five years compared with the first, and over the third compared with the second; over the fourth five years there was considerable decline, but over the last four there was again increase, though not bringing up the quantity to that of the third period, 1881–85. Victoria seems to be both the greatest producer and the greatest exporter, South Australia coming second, and New Zealand third, but declining in production in recent years. Next comes New South Wales as a producer; Tasmania, Queensland, and Western Australia, supplying immaterial amounts. It is stated that, in the best yielding Colonies, there is a good deal of land suitable for the crop, but a deficiency of labour to utilise it profitably for the purpose; whilst, excepting in New Zealand, the yield per acre is generally so small that the gross return for a given area leaves comparatively little profit. Lastly, as to the position of wheat production in the Australian colonies under existing conditions. It seems that, chiefly owing to drought, there will probably be a serious falling off in this year's crop, New South Wales, South Australia, Queensland, and especially Victoria, having suffered considerably; whilst wheat and flour are already being imported from the United States into some of the Colonies. Upon the whole, it would seem that the prevailing low prices can afford little inducement to extension of wheat growing for export; though with higher market values further development would be probable.

Russia.

Russia in Europe is the largest exporter of wheat in the world excepting the United States; but even including Russia in Asia the Empire exports considerably less than the United States. Russia in Europe, like other exporting countries, has exported increasing amounts since the period of the bad harvests in the United Kingdom and Western Europe between 1871 and 1881. In 1878 the exports were very high, but then they moderated and fluctuated for some years, until, in 1888, they were higher than ever before. Since then they have kept at a high level, excepting in 1892 and 1893, after the failure of the crop in 1891. The heaviest exports were, however, in 1895,

notwithstanding the very low prices at the time. Indeed, the exports from Russia in Europe in that year were very nearly as high as those from the United States in the year ending June 30, 1895. The records at present available indicate that they will be lower in 1896 than they were in 1895, and that those for 1897 will be lower than average.

Taking the five-yearly periods commencing 1871, the average annual amount of the exports was greater over the second period than the first, greater over the third than the second, greater over the fourth than the third, and the greatest over the fifth and last period. This was the case notwithstanding the declining prices, and the low exports in two of the five years—1892 and 1893, after the famine in 1891. In fact, in spite of considerable fluctuations from year to year, doubtless in great part due to seasons, and other local conditions, and not very clearly traceable to rise or fall in price, there has been gradual progression during the twenty-five years of our review. It is, however, stated that the prevailing low prices have been a cause of much distress and discouragement to the producers. On the other hand, it is said that great efforts are being made to improve the methods of production, State aid being given in various ways; whilst there still remain considerable areas of fertile land to be brought under cultivation. It is, indeed, assumed that if prices become more remunerative, there will be increased production of wheat for export. But it is admitted that, besides improved methods of production, better roads, more railway facilities, and lower freights, are needed to maintain successful competition with other exporting countries.

Russia in Europe is, indeed, a very important factor to take into account; and an element for consideration is that much of the exports come from large tracts of rich soil. Further, so far as records are at command, it would appear that the exports from Russia in Asia, though bearing only a small proportion to those from Russia in Europe, have nevertheless increased considerably in recent years, doubtless aided by improved communications; and, although the proportion of the whole is small, the exports of meal and flour reckoned as wheat, have increased proportionally more than those of wheat as wheat. Upon the whole, there can hardly be much doubt that with more remunerative prices, increased exports from the Russian Empire would be forthcoming.

Austria-Hungary.

Of the total production of wheat in Austria-Hungary, from three-fourths to four-fifths are due to Hungary; and of the

total exports frequently nearly, and sometimes fully, one half is represented by flour. Wheat is, however, imported into Hungary (though in smaller quantities in recent years than formerly), from Roumania, Servia, and Russia, and some from other countries, chiefly for milling purposes. The exported flour is said to be derived mainly from Hungarian wheat, whilst the flour from the imported wheat is to a great extent appropriated to home consumption. As the Table shows, the net exports were fairly large in the first year, 1871, but then for five years the exports were either overbalanced by imports, or the net exports were but small. There was then an increase for three years, followed by an excess of imports in 1880, and very little surplus exports in 1881. From that time, for nine or ten years, there were fair, but variable, and, in a few years, even large amounts of net exports; but during the last few years they have very rapidly diminished. The general result is, that over the first five-yearly period the net exports were very small, over the second and third periods they were considerable, over the fourth about twice as much as over either the second or the third, but over the fifth and last period they were very low. It may be added that, of the total exports, an average of between 40 and 50 per cent. is represented by flour reckoned as wheat.

Upon the whole, the exports of wheat, and of flour reckoned as wheat, from Austria-Hungary showed, in spite of fluctuations, a general tendency to increase up to within the last few years, during which they have declined in a very marked degree. As, according to published records, the area, and the aggregate crop, have increased in recent years, and it is to be supposed that the activity of the mills has not declined, the assumption, which is borne out by such evidence as is available as to supplies and population, is that, with increasing population, and low prices inducing a wider and freer use of wheaten products as food, the demands for home consumption have left but little surplus for foreign markets. It results that the exports from Austria-Hungary do not constitute an important element in the world's supply for other countries; but they are characterised by comprising a large proportion of flour of high quality.

Roumania.

The Table shows that the returns for Roumania do not commence until 1879, and so relate to only seventeen years, 1879–95 inclusive. Comparison will show that in nearly all of these individual years, the exports of wheat, and of flour reckoned as wheat, were higher from Roumania than from Austria-Hungary, and this was especially the case during the

later years, in which the exports from Austria-Hungary declined so considerably, whilst those from Roumania maintained a high level. The year of highest exports from Austria-Hungary was 1888, from which date they rapidly declined. The period of highest exports from Roumania was over the eight years 1888–95, during which they never fell below 3 million quarters, whilst in one year they approached, and in three years considerably exceeded, 4 million quarters. In fact, as already stated, Hungary imported from Roumania. On the other hand, Roumania is supposed to obtain some of her supplies from Bulgaria and Servia. Hungary is, however, estimated to produce about two and a half times as much wheat as Roumania; but Roumania produces more in proportion to population, in other words has a larger surplus for export.

Some Other Exporting Countries.

Excepting some of the South American Republics, which will be referred to separately, Bulgaria, Servia, Eastern Roumelia, Turkey in Asia, and Egypt, perhaps come next in importance as exporting countries to those already considered; but none of them supplies large amounts, and, in the aggregate, they export considerably less than Roumania; nor does their estimated production in relation to population indicate much surplus for export. Under more favourable political conditions, and with improved communications, it is probable that the exports from Asia Minor might be considerably increased. The production in Egypt is small in relation to population, and, in districts suitable as to soil and climate, both production and export are probably capable of extension. Upon the whole, however, the group of countries enumerated does not promise material extension in the near future.

Argentina.

Argentina, Chili, and Uruguay are of special interest in connection with the subject of the wheat production of the world, not so much from the amounts that they have hitherto exported, but because of the rapid increase in the production and export (especially of Argentina and Uruguay) within recent years, and of the probabilities of extension in the future. The Table shows that Argentina has exported more or less from the commencement of the period of twenty-five years under review. In six of the first twelve years there were only quite immaterial amounts of net exports, whilst in the other six the imports overbalanced the exports. From 1883 up to the present time, however, the net exports have continued to increase, and very rapidly during the

last six years—from more than 1½ million quarters in 1890 to more than 7½ million in 1894, and to nearly 5 million in 1895. In fact, there has been great increase in the area under the crop within the last few years; and it is said that although low prices have been much felt, leaving comparatively little margin for profit, yet it is considered that with improvement of methods cost of production will be reduced; and it is believed that the equipment for wheat growing is now so fully established, that, even with continued low prices, there would not be material reduction of area for some time to come. On the other hand, it is alleged that, with remunerative prices, the area under the crop might be increased even twenty-fold! There is plenty of fertile soil as yet not broken up, and labour is cheap; but for material extension in this direction much greater road and railway facilities, and increased storage arrangements, would be required. Greatly increased production on such lines could therefore only be slowly developed. Upon the whole, however, it cannot be doubted, that Argentina comprises very large areas of fertile land suitable for wheat production for export; which, if prices gave sufficient encouragement, would probably be gradually brought into requisition, as the necessary conditions of utilisation were available.

Chili.

Chili, although comprising a very large total area, does not include a large proportion with soil and climate suitable for wheat production. The Table shows, however, that Chili has exported considerable quantities of wheat for many years past. Our records commence only with 1875, but, during the twenty-one years to 1895, there has been more or less fluctuation in the amount of exports; though, upon the whole, they have shown a degree of regularity which does not indicate active development. Indeed, the records for the last five years do not show material increase compared with some earlier years. But that there is a considerable area still available for wheat production seems to be certain.

Uruguay.

Uruguay is a comparatively small State; but agriculture, and especially wheat production, has been considerably developed in recent years, and there are large tracts of land suitable for extension, only requiring remunerative prices, capital, labour, and better communications, for utilisation. The Table shows that Uruguay has exported wheat and flour for a good many years; but that until quite recently the quantities have been small, and sometimes overbalanced by imports. Activity seems to have recommenced in 1893, from which date the net

exports have considerably increased, reaching nearly ¾ million quarters in 1894, and more than ½ million in 1895. But the evidence at command indicates that the exports will probably be less in 1896 and 1897. As already said, there are large areas of fertile land awaiting favourable conditions for utilisation.

Summary and General Conclusions.

From a review of the whole of the facts which have been adduced, it is evident that the deficient yields of wheat in most years from 1871 to 1882 in the United Kingdom, and sometimes in Western Europe also, and the consequent rise of prices, stimulated its production for export in various countries throughout the world. In some this led to the opening up of large tracts of land, and sometimes of very rich land, for the purpose, involving very large investments of capital. The result has been so full a supply in relation to the demand as greatly to depress prices, and so to discourage the further rapid extension in some of the chief exporting countries in recent years; whilst some others have rapidly developed even coincidently with the declining prices. The evidence points to the conclusion that, in the case of some of the larger exporting countries, the continuance of low prices, and other adverse circumstances, will probably retard extension in the near future; whilst, in others, extension seems more probable, even in spite of low prices.

At any rate, it cannot be doubted that there remain throughout the world great inherent capabilities for increased production, which would rapidly be developed with rising prices. Such, indeed, is the extent of this capability that the encouragement of higher prices would, by increased production and increased export, tend to keep the supply fully up to the demand, and so far to react adversely to any considerable and permanent rise. There will, of course, be fluctuation in prices from year to year, according to the varying relation of supply to demand, depending on the seasons and other circumstances in different countries. Of this we have an illustration at the present time. Commencing with October last there has been a slow though steady rise in prices. Whatever other agencies may have been at work, it may be stated that the rise has followed what official statistics indicate to have been an average reduction of area under wheat in the United States—the greatest exporting country—of about four million acres per annum over the four years 1893–96, compared with 1892, and of five and one-third million compared with 1891. the year of highest recorded area; and the Table shows that,

after the high exports in the years ending June 30, 1892 and 1893, following the production of the extended areas of 1891 and 1892, the exports were much less in 1894, and less still in 1895; whilst subsequent records show that they were still further reduced in the year ending June 30, 1896; and recent information indicates that they will probably be less for the year ending June 30, 1897. Then, parts of British India are on the borders of famine, and the country is importing wheat instead of exporting; whilst, though of less importance, some of our Australian Colonies are also importing instead of exporting. Further, it is estimated that the exports from Argentina will be considerably less in 1896 than they were in 1895, and probably also less in 1897. Lastly, what is of more importance is, that the exports from Russia in 1896 will probably be less than those of 1895, and that, if the figures hitherto published are to be relied upon, the crop of this year will be less than average.

The average price of wheat in our own country began to show serious tendency to decline in 1892, when the world's exports had reached a higher level than ever before; but it was at its lowest from September, 1894, to May, 1895, coincidently with still higher exports. The records and estimates already available would indicate, however, that, under ordinary circumstances, the total export supplies of the world would be considerably less in 1896 than the average of the four preceding years, and probably less still in 1897. On the other hand, prices for future deliveries show little change as the spring advances, as if no deficiency were expected; the assumption presumably being that the higher prices will cause economy, reduction of stocks and reserves for home consumption, and perhaps extension of area sown, in exporting countries.

To what extent, or how long, therefore, the circumstances enumerated will have an influence on the price of wheat, or whether others will arise tending to maintain or to counteract the present movement, remains to be seen. No doubt, under the influence of extensive war, involving powerful nations and large populations, there would be more or less rise in prices, for a longer or shorter period. But, independently of any such calamity, or other abnormal contingency, such is the extent to which the wheat-producing capabilities of the world have been opened up, and show possibilities of development, that it cannot be said that the circumstances indicate much prospect of a substantial and permanent rise.

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Rothamsted.

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THE ROYAL COMMISSION

ON

AGRICULTURAL DEPRESSION

AND THE

VALUATION OF UNEXHAUSTED MANURES.

BY

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THE ROYAL COMMISSION ON AGRICULTURAL DEPRESSION AND THE VALUATION OF UNEXHAUSTED MANURES.

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THE FINAL REPORT AND RECOMMENDATIONS OF THE COMMISSION.

IT is only reasonable to expect that the Report of a Royal Commission appointed to inquire into the subject of Agricultural Depression, which sat for nearly four years, held 177 meetings, examined 191 witnesses, and have put on record a number of conclusions and recommendations, should sooner or later be followed by legislation. Nor can it be wondered at that the Agricultural Holdings Act of 1883, which brought legislation to bear upon an entirely new subject, should have caused dissatisfaction to many of those whose interests might be affected by its provisions. Indeed, when the Judges of one Court differ from those of another in their interpretation of the law, and even those in the final Court of Appeal are sometimes divided in their view, little surprise can be felt that a claim on one side for compensation under the Act should be met by an appeal or larger claim on the other side; or that the ultimate result should be unsatisfactory and expensive to both parties concerned. Nor can the opinion which has been expressed by some farmers—"that any fool can be a valuer"—be held to establish any serious ground of reproach against those who have been called upon to act in that capacity, when it is considered that they had little or no experience to guide them.

Among the changes which the Commissioners recommend as subjects for future legislation, those which appear to be of the most importance may be briefly summarised as follows:—

Much greater simplicity, and much less expensive procedure, in the settlement of claims as between the owner and the occupier of the land.

Removal of some of the restrictions still embodied in

some agreements, as to the cultivation of the land, and the disposal of the produce.

Compensation to be allowed to the tenant for the consumption by cattle, sheep, and pigs, of corn produced on the holding; also in respect of corn consumed by horses other than those regularly employed on the farm.

Removal from Section 1 of the Agricultural Holdings Act (1883) of the proviso recognising "the inherent capabilities of the soil," a term which appears to the Commissioners to be obnoxious to many, as they are confident that Referees in estimating the tenant's interest in the value of an improvement will take into consideration the character of the soil, its natural fertility and capabilities, without any instruction by statute.

It is somewhat remarkable that the term "cumulative fertility" is also objected to. Thus in the course of the discussion at the Conference of the Scottish Chamber of Agriculture held in Edinburgh on October 20, Mr. T. H. Elliott, Secretary to the Board of Agriculture, is reported to have expressed a strong objection to the term "cumulative fertility." He said that the phrase used to haunt him a little; he met it at every turn, and he did not know what it meant; and he was glad that it had disappeared from the resolution.

As in the case of the term "inherent fertility," which the Commissioners propose should be abandoned, as valuers must recognise the fact even without any instruction by statute, so in the case of the term "cumulative fertility" neither owners nor occupiers will quarrel about the term, provided that which it is intended to define is fairly valued. It is indeed, satisfactory to know that the two members of the Commission who did not sign the Report, but submitted separate reports embodying their own views, while advocating greater freedom to the tenant in his operations, both urge the importance of maintaining the fertility of the soil. Thus, Mr. Lambert, in his own "*General Conclusions*" (h, p. 224), says that the tenant should have "freedom to crop the land and sell the produce, provided the fertility of the soil is maintained." And Mr. Channing, in his own "*Recommendations*" (10, p. 369), says "tenants should be free to cultivate the land and sell produce to the best advantage, so long as they maintain its fertility."

No one can doubt that the soils of Great Britain vary very greatly in their character and composition—from the lightest soils in Norfolk, which practically require the whole, or even sometimes more than the whole, of the food taken up from the soil by the growing crops to be supplied from external sources, to

the deep alluvial soils which are very rich in fertility, not only on the surface, but to a considerable depth. The majority of the soils of the country are neither so poor nor so rich as those above referred to; but, in many districts, continuous good farming is to be found. It is chiefly those who depend upon town manures, or the products of other countries in the form of cakes, corn, &c., and who know that to accumulate fertility in the soil, or in other words to bring the land into condition, is a work of time, and involves considerable outlay, who are looking forward to legislation to protect their interests.

As part of the Rothamsted Estate has been devoted to exact experiment for a longer series of years than any other land, and as it does not differ much in character and in *inherent fertility* from that over a considerable area of the district, it will be of interest briefly to refer to its previous history as shown by the records available. There is evidence that as far back as the early part of the sixteenth century most of it was already under arable cultivation, partly in the hands of the owner, and partly in that of tenants. The Manor House was even then old, the Manor of Rothamsted dating back to a very early period. It may be assumed, therefore, that much of the land has been under arable cultivation, such as it was, for some centuries. Coming to more recent times, it is found that in 1802 the rent of the estate was raised to 20*s.* per acre, the tenant paying the tithe. This rental continued without change up to 1822, when it was reduced in consequence of the great fall in the price of corn, and the return to money payments. The tenants held the farms as annual tenants, leases not being customary in the district; and the agreement signed by the tenant bound him to farm according to the custom of the country.

The custom comprised a five-course rotation of turnips, barley, clover, wheat, and oats; peas, beans, or summer fallow, being admissible instead of the clover. The tenant might sell the wheat, barley, peas, and beans, but was to consume all hay, straw, roots, and green crops on the holding; excepting that he might sell off hay, wheat-straw, and one-fifth of the roots, on condition that he brought back for every load of such produce sold or carried off, one ton of good dung or other manure of equal strength and value. More recently the consumption by cattle, sheep, or pigs of purchased feeding-stuffs has been deemed an equivalent to manure.

Up to nearly the middle of the present century, artificial manures were but little used. There can be no doubt that for a very long period—in fact from the time when the land was broken up and subjected to arable cultivation—there was a

gradual removal and loss of some of the constituents of the soil. So far, for example, as the nitrogen is concerned, it is certain that the amount of it contained in the surface soil is considerably less in its present arable condition than it was before it was broken up. In fact, as we have said elsewhere, "When it is borne in mind that all our arable soils were originally covered with natural herbage or timber, and that during centuries of arable culture much of the previously accumulated fertility has thereby been removed, it will readily be understood that in the re-conversion of such arable land into permanent grass, much of the used-up accumulated fertility must be restored, before we can get it back into a satisfactory condition."

It is obvious that, under the system which has been described, a slow exhaustion of the soil must have been taking place for centuries; and, doubtless, exhaustion to a greater or less extent must have taken place over large areas of Great Britain. The limits of reasonable exhaustion are indicated in some measure by the character of the rotations adopted, whether a four, a five, or a seven year course. In some districts, however, the tenant is required to apply lime to the soil periodically; but as the action of lime is to liberate fertility, when it is said that the land has been overlimed, the explanation is that the resources of the soil have been overtaxed.

Let us now consider how far soils are competent to yield profitable crops over long periods of time from their own resources. In the first place, it will be well to point out what is the average proportion of the constituents of our crops which is derived from the resources of the soil, and how much is obtained from the atmosphere. Leaving out of consideration for the present the nitrogen, which will be considered independently, it may be said that the amount of mineral or incombustible matter taken up in the crops of a four-course rotation would only be about 5 or 6 per cent. of the total produce; the remainder consisting of non-nitrogenous combustible matter derived from the atmosphere, and water. As to the important constituent of soils, manures, and crops—the *nitrogen*—there is a constant loss of it from the soil, greater or less according to circumstances, in the form of nitrates passing off in the drainage water; and there are also other losses of it from the soil or from the manure. Part of this loss to the soil and to the growing crops is, however, compensated by the fixation of free nitrogen coincidently with the growth of leguminous crops.

Thus, stated in a few words, the conditions as between the owner and the occupier appear to be, that the owner supplies the use of a house, farm-buildings, &c., and the land, which

supplies mineral constituents and a certain amount of nitrogen, by the aid of which the growing crops are enabled to accumulate a large amount of their material from the atmosphere, and the occupier is allowed to remove and take to market so much of the produce as long experience has proved can be done without injuriously exhausting the "inherent" capabilities of the soil.

Let us now try to illustrate the extent, and the limit, of the capabilities of a soil of a certain description, by reference to the results of experiments conducted on the Rothamsted soil, with different crops, for many years. The soil is a rather heavy loam, naturally drained by the chalk which occurs at a varying depth of from 10 to 20 feet from the surface. Just below the reach of the plough there is a yellow clay, containing many flint stones; and if the clay be brought to the surface it is found to be very injurious to vegetation.

Looking upon the subject from a chemical point of view only, it would seem that a complete analysis of the soil upon which crops were to be experimentally grown should be one of the first things to undertake; and soon after the commencement of our systematic field experiments, the importance of the subject was very carefully considered. Having regard, however, to the points which it seemed desirable to ascertain, and to the inapplicability of the methods of soil analysis then adopted to determine what was wanted, we decided that for the time the most promising line of investigation was to confine attention almost exclusively to the nitrogen of the soil, and to be satisfied to take and preserve samples of the experimental soils for future investigation, when more was known of what a soil either is or ought to be, and when methods of analysis were available for determining what it was desired to know.

A few years ago Dr. Bernard Dyer made a step in advance by devising a process with the view of determining not only the total constituents of a soil, but as far as practicable how much of the most important constituents—the potash and the phosphoric acid—was probably in a condition of availability to growing crops. It is obvious that, for the purpose of such an investigation, the Rothamsted soils, which had been subject to known conditions as to manuring and cropping for many years, would be found to be very valuable material for such an inquiry. Accordingly, Dr. Bernard Dyer was provided with a series of samples taken from the different plots of our experimental barley field; and in 1894 he published an interesting paper on the subject. He has since been supplied with samples from the different plots, taken at different periods, and at different depths, from the field which is now growing the 55th crop of wheat in

succession on the same land. The analyses of these soils are substantially completed, and it is anticipated that the results will soon be published. Without going into any detail, it may be said that within the reach of the roots of our crops there still remain many thousand pounds per acre of each of the three most important constituents of crops—nitrogen, phosphoric acid, and potash. By far the greater part of these exists in the soil and subsoil in a condition not available to crops; but a small proportion is annually liberated by the aid of tillage operations and atmospheric action, and the degree in which one description of soil compared with another is capable of yielding up the required constituents to crops, is to a great extent a measure of its relative fertility.

So far we have referred to a class of soils of which there is evidence that they have yielded remunerative crops from their own resources for a long period of time. It is not to be assumed that the cultivators of such soils at the present time do not in a greater or less degree have recourse to fertility brought from without in the form of cattle foods or manures. There is, however, a large class of soils which are in themselves so deficient in the constituents essential for the growth of good crops, that they cannot be profitably cultivated without a large import of fertility. It is the large body of farmers who cultivate land of this description, and also those who, though cultivating a better class of soils, grow upon them much larger crops than the natural resources of the soil are competent to yield, who are anxious to have provided for them, simple and inexpensive means, by which their share in the soil capital can be secured to them.

In our paper—"On the Valuation of Unexhausted Manures"—published in this Journal in 1885, we illustrated the application of the valuations by reference to the case of a farm cultivated under a four-course rotation with the sale of only grain and meat. Even with these limitations the subject was found to be not without its difficulties. If, however, the recommendations proposed by the Royal Commission are embodied in a new Act, and under it the farmer may grow and sell what he pleases, and receive compensation for the consumption of home-grown produce which he might otherwise sell, it is obvious that the questions arising will be more complicated, and that the difficulties of the valuer will be considerably increased. In the hope that it may prove of some assistance to those who may be called upon to decide, as between the owner and the occupier of land, complicated questions of underground values, we propose to give some

illustrations of accumulation, and of exhaustion, from the results of our experiments on the application of various manures to different crops.

Illustrations of Accumulation and of Exhaustion of Fertility.

In 1856 experiments were commenced on a piece of old permanent grass-land, being a portion of the Park at Rothamsted, with a great variety of manures. One plot (3) has been continuously unmanured for more than forty years; first crops only being removed over the first twenty years, but first and second crops (if any) over the second twenty years. Another plot (2) received fourteen tons of farmyard manure per acre annually for eight years in succession, and it has since been left unmanured. As to mowing and removal of the crops, it was treated in the same way as the permanently unmanured plot. The following Table gives the average annual produce of hay per acre on each of the two plots, over the eight years in which plot 2 received farmyard manure, over the next twelve years, and over the succeeding twenty years.

Table I.—*Experiments with Farmyard Manure on Permanent Grass-land.*

	Unmanured every year	Farmyard manure, 8 years 1856–63; unmanured since	Plot 2 more than Plot 3
	Plot 3	Plot 2	
	cwt.	cwt.	cwt.
8 years, 1856–63 (1st crops only) .	23¾	42⅞	19⅛
12 „ 1864–75 „ „ .	19⅝	32⅜	13¼
20 „ 1876–95 (1st, and 2nd crops if any)	25⅞	29⅞	4

It will be seen that over the eight years of the application of the manure, the dunged plot gave an average of 19⅛ cwt. of hay per acre per annum more than the unmanured plot. Over the next twelve years, without any further manure, the residue of the dung gave an average of 13¼ cwt. more than the permanently unmanured plot. Lastly, over the succeeding twenty years, the dung-residue gave an average of 4 cwt. per annum more than the unmanured plot; and it may be added that in only one year of the twenty, in 1893, a year of drought, did it give less produce than the unmanured plot. It is true that the application of 14 tons of farmyard manure per acre per annum for eight years in succession is an unusually heavy dressing;

but it is of interest to know that the residue was very materially effective for some years, and that it was more or less so for thirty-two years after the application. In fact, the details show that, over the first six years after the cessation of the application, there was as much average annual increase of produce over the unmanured, as over the eight years of the annual application. From that time, however, it declined considerably.

Another illustration of the effect of the accumulated fertility due to a large application of farmyard manure is afforded by our experiments on the continuous growth of barley. For twenty years, from 1852–1871, 14 tons of farmyard manure were annually applied to one plot (7). The application was then discontinued on one half (7–1), but continued on the other half (7–2), and the experiment has now been so continued for twenty-five years, to 1896 inclusive. The following Table summarises the results; and it also gives for comparison the produce without manure, and that by a mixed mineral manure containing superphosphate and salts of potash, soda and magnesia, but no nitrogen. The results are those of the dressed grain.

TABLE II.—*Experiments with Farmyard Manure on Barley.*

——	Unmanured every year	Mixed mineral manure every year	Farmyard manure		Plot 7–1 Farmyard Manure 20 years; afterwards unmanured		
			Every year	20 years 1852–71; unmanured since	Less than plot 7-2	More than unmanured	More than mixed mineral manure
	Plot 1-0	Plot 4-0	Plot 7-2	Plot 7-1			
	bushels	bushels	bushels	bushels	bushels	bushels	bushels
20 years, 1852–71	20	27½	48½		—	—	—
20 „ 1872–91	13¼	17¼	49	30½	−18¾	+17	+13
5 „ 1892–96	11⅛	15	50¼	24⅛	−26⅛	+12⅝	+ 9⅛
25 „ 1872–96	12⅞	16⅝	49¼	29	−20¼	+16⅛	+12⅛

It is seen that over the first twenty years after the cessation of the application on plot 7–1, it yielded an average of 30½ bushels of barley per acre per annum, which was, however, 18¾ bushels less than on plot 7–2 with the continued application; but it was 17 bushels more than on the permanently unmanured plot, and 13 bushels more than on the plot with a full mineral manure without nitrogen. Over the next five years the deficiency compared with the produce where the application was continued was 26⅛ bushels per acre per annum; but there was still 12⅝ bushels more than on the unmanured plot, and 9⅛ more than on the plot with the full mineral manure. Or,

taking the effect of the residue on plot 7–1 over the twenty-five years since the application, the result was a deficiency of 20¼ bushels per acre per annum compared with plot 7–2 with the continued application; but an excess of 16⅛ bushels over the permanently unmanured plot, and of 12⅛ bushels over the purely mineral manured plot. In reference to these comparisons it is to be borne in mind, as shown in the Table, that both the unmanured produce and that by mineral manure have gone down considerably from period to period, so that the increase given as due to the residue on 7–1 is over a reduced produce without manure and by mineral manure.

Lastly in regard to the reduction of produce after the cessation of the annual application of farmyard manure, although the effect of the residue was very marked, it somewhat rapidly declined, notwithstanding that there was still a very considerable accumulation within the soil, of nitrogen as well as of other constituents. How, then, is so large a reduction of produce to be accounted for? The nitrogen of farmyard manure exists in very different conditions. That due to the urine of the animals will be the most rapidly available; that in the finely comminuted matter in the solid excrements will be much more slowly available; and that in the litter will be still more slowly available. Hence the small proportion that is at once effective, and the very large amount that accumulates within the soil in a very slowly available condition. But the evidence at command leads to the conclusion that neither in the wheat-field nor in the barley-field does the accumulation within the soil account for the whole of the nitrogen supplied which has not been recovered in the increase of crop. Some is doubtless lost as nitrates by drainage; and, in the presence of so much organic matter, some is no doubt lost by evolution as free nitrogen. The fact of such losses is of considerable interest, but it is some consolation to believe that the loss, both by drainage as nitrates, and by evolution as free nitrogen, will be proportionally much less in ordinary farm practice, where the amounts of farmyard manure applied are much less, and where various crops, with different root-ranges, and different periods of accumulation, are grown.

In the same experimental barley-field, experiments have also been made with another organic manure, namely, rape-cake, which was applied at the rate of 2,000 lb. per acre per annum over the first six years, 1852–57 inclusive, and of 1,000 lb. per acre each year since; corresponding in all to about 20½ tons per acre over the forty years, 1852–91. In each year there were four rape-cake plots: No. 1 with rape-cake alone; No. 2 with rape-cake and superphosphate; No. 3 with rape-cake and salts of

potash, soda, and magnesia; and No. 4 with rape-cake, and both superphosphate and the salts of potash, soda, and magnesia. The Table (III.) shows the amounts of dressed grain yielded per acre per annum, over the first 20, the second 20, and the 40 years, on each of these four plots; and also, for comparison, the produce on each of four plots, respectively with nitrate of soda alone, and with the nitrate and the same mineral manures as in the case of the rape-cake plots.[1]

TABLE III.—*Experiments with Rape-cake on Barley.*

	Plot 1 (No mineral manure)		Plot 2 Superphosphate and		Plot 3 Sulphates of potash, soda, and magnesia, and		Plot 4 Mixed mineral manure (2 and 3 together) and	
	Rape-cake	Nitrate soda	Rape-cake	Nitrate soda	Rape-cake	Nitrate soda	Rape-cake	Nitrate soda
	bushels	bushels	bushels	bushels	bushels	bushels	bushels	bushels
20 years, 1852–71	45¼	37	46¾	49¼	43⅝	37⅜	47⅜	49¾
„ 1872–91	37⅛	28⅜	40	42¼	35⅝	29½	39	41¼
40 „ 1852–91	41¼	32¾	43⅜	45¾	39½	33½	43¼	45½
2nd 20 years less than 1st 20 years	8⅛	8⅝	6¾	7	8	7⅛	8⅜	8½

The Table shows that when the rape-cake and nitrate of soda were respectively used alone, the rape-cake, which itself contains some phosphate and potash, yielded an average over the forty years of 41¼ bushels of grain, against only 32¾ bushels with the nitrate. When each of the two manures was used with superphosphate in addition, the rape-cake plot yielded an average of 43⅜ bushels, against 45¾ on the nitrate plot. When salts of potash, soda, and magnesia were applied with both the rape-cake and the nitrate, the rape-cake plot gave 39½ bushels against only 33½ on the nitrate plot. Lastly, when both superphosphate and salts of potash, soda, and magnesia were used, the rape-cake gave an average of 43¼ bushels, against 45½ on the nitrate plot. These results show that the addition of phosphate to the two nitrogenous manures increased their produce much more than did the salts of potash, soda, and magnesia.

Comparing the produce over the second twenty years with that of the first in each case, it is seen that with both manures there was very considerable reduction of produce over the second period compared with the first, and the difference was

[1] First 16 years of the 40, the "nitrate" plots received ammonium-salts instead of nitrate. First 6 years, 400 lb. ammonium-salts against 2,000 lb. rape-cake; next 10 years, 200 lb. ammonium-salts against 1,000 lb. rape-cake; last 24 years, 275 lb. nitrate of soda (equal in nitrogen to 200 lb. ammonium-salts) against 1,000 lb. rape-cake.

substantially the same, whether rape-cake or nitrate (or its equivalent of ammonia) was used as the nitrogenous manure. The reduction was, in fact, in both cases mainly due to less favourable seasons.

The rape-cake contained rather more nitrogen than the nitrate, but in a less rapidly available condition; and the fact that, notwithstanding analyses showed a considerable residue of nitrogen from the rape-cake within the soil, and also some of phosphoric acid and potash, there should still be practically as much reduction of produce over the second twenty years as with the nitrate, is evidence that the residue left from the rape-cake became very slowly available.

It may be added, however, that both the proportion of grain to straw, and the weight per bushel of the grain, were, under each of the four conditions as to mineral manure, considerably higher in the produce by the rape-cake than in that by the nitrate. In regard to the little evidence of beneficial action of the nitrogenous and mineral residue proved to have been accumulated within the soil where the rape-cake was used, it is probable that in somewhat heavy soils generally, as in the case of that at Rothamsted, the residue from rape-cake will become less rapidly available than it would in lighter and more porous soils.

The next Table affords a very remarkable illustration of the effect of accumulation due to long continued application of farmyard or stable manure. On a portion of ground at Rothamsted which had been under ordinary kitchen garden cultivation for probably two or three centuries, involving the application of frequent and large amounts of farmyard or stable dung, red clover was sown in 1854, and has yielded large crops for more than forty years. The following is a summary of the estimated average annual produce of clover hay per acre, and of nitrogen in it, over each ten yearly period of the forty years.

TABLE IV.—*Experiments with Red Clover on rich Garden Soil.*

	Clover hay per acre per annum	Nitrogen per acre per annum (estimated)
	cwt.	lb.
10 years, 1854–63	95½	257
„ 1864–73	49⅝	133
„ 1874–83	45½	122
„ 1884–93	46½	125
40 „ 1854–93	59¼	159

It is seen that there was an average produce per acre per annum as clover hay, of 95½ cwt. over the first ten years, of 49⅝

cwt. over the second, of 45½ cwt. over the third, of 46½ cwt. over the fourth, and of 59¼ cwt. over the forty years. Now, even the amounts over the later periods correspond to what would be considered fair, though not large, crops when clover is grown in an ordinary course of rotation only once in four or eight years or more; so that the produce over the first ten years on this rich garden soil was very unusually heavy. Indeed, the average annual produce over the whole period of forty years, namely, 59¼ cwt., or nearly 3 tons of hay, would be a very good yield for the crop grown only occasionally in the ordinary course of agriculture.

But it is when we look at the figures in the last column of the Table, which show the estimated amounts of nitrogen in the crops, and compare these with those obtained on ordinary arable land, that the importance and significance of the results are recognised. Thus, the amount of nitrogen in fair crops of wheat, barley, or oats, will be from 40 to 50 lb. per acre, of beans about 100 lb., of meadow hay about 50 lb., and of clover grown occasionally in rotation from 100 to 150 lb. But here, on rich garden soil, the produce of clover has, in one year, contained more than 400 lb. of nitrogen, in three years more than 300 lb., in several more than 200 lb., and in only thirteen of the forty years less than 100 lb.; whilst, as the Table shows, the estimated average annual yield of nitrogen in the above-ground growth was, over the first ten years 257 lb., over the second 133 lb., over the third 122 lb., over the last ten years 125 lb., and over the whole period of forty years 159 lb. Further, the averages over the second, third, and fourth ten yearly periods of the continuous growth of red clover were about as much as a fair, but not a large, crop grown occasionally under the ordinary conditions of agriculture; whilst the average of the forty years is as much as in a really good crop grown occasionally in rotation.

In reference to the above extraordinary amounts of red clover grown for forty years in succession on rich garden soil, and of the large amounts of nitrogen in it, it may be stated that, in 1857, after the removal of the crops of the fourth year of the experiments, the surface soil, nine inches deep, was found to contain nearly four times as much nitrogen as the average of the Rothamsted arable soils to the same depth, and nearly five times as much as the exhausted arable land where red clover had failed. The garden soil would also be correspondingly rich in all other constituents. Samples of both the first and the second nine inches of soil were taken in 1879, and in 1896. As to the surface soil, the results show a very considerable reduction in the stock of nitrogen in it from period to period; the

rate of reduction being much greater over the twenty-one years of crop from 1857 to 1879, than over the seventeen years from 1879 to 1896. That is to say, coincidently with the very marked decline in the clover growing capability of the soil, there was a great reduction in the stock of nitrogen in the surface soil. Further, with the reduction in the stock of nitrogen in the soil, there was not only a reduced amount of produce, but a reduced persistence of the plant, much more frequent sowings being required.

It may be added, that the loss of nitrogen by the surface soil was estimated to be more than one-third of the total amount it contained at the commencement; but the reduction was not sufficient to account for the whole of the nitrogen removed in the crops. The evidence points to the conclusion, however, that the resources of the subsoil, which was found to be very much richer than the corresponding depth of the Rothamsted ordinary arable soils, also contributed a share to the result.

But when excessive amounts of farmyard manure are employed, there may be more or less loss by the evolution of free nitrogen; and so far as this may have occurred, there will be the less of the ascertained loss of the soil to be credited to assimilation by the growing crop. On the other hand, as nodules are found on the roots of the clover growing on the garden soil, it is to be concluded that some of the nitrogen of the crops was derived by fixation of free nitrogen under the influence of the microbe action within the nodules. Nevertheless, there can be no doubt, that the large amounts of clover grown, and of nitrogen taken up, were mainly due to the very great accumulations of fertility from the applications of unusually large amounts of farmyard manure over a long period of time.

The instances which have so far been given of the accumulation of fertility within the soil from the application of farmyard manure, obviously relate to cases of accumulation far in excess of those which take place when such manure is applied in the much smaller quantities usual in ordinary agriculture. Still the illustrations are not without interest and significance, and are worthy of the attentive consideration of those who are called upon to estimate underground values.

We will now direct attention to some instances showing the amounts, and the limits, of the productive effects of the residue when crops are grown by the use of a full mineral manure with the addition of moderate, and of excessive, amounts of nitrogenous manure in the form of ammonium-salts. For thirteen years, from 1852 to 1864 inclusive, wheat was grown on four

plots in the experimental wheat-field, each of which received the same mixed mineral manure, containing potash, soda, magnesia, and superphosphate; on one (5) with the mineral manure alone; on another (7) with the addition of 400 lb. of ammonium-salts; on the third (8) with 600 lb.; and on the fourth (16) with 800 lb. of ammonium-salts, in addition to the mineral manure. At the expiration of the thirteen years, however, the application was entirely stopped on Plot 16 with the very excessive amount of ammonium-salts, and it was then left unmanured for nineteen years; whilst the same applications as before were continued on the other 3 plots. The following Table summarises the quantities of dressed grain yielded.

TABLE V.—*Experiments on Wheat, with Artificial Manures.*

	Mixed mineral manure				Plot 16		
——	alone	and ammonium-salts = 86 lb. nitrogen	and ammonium-salts = 129 lb. nitrogen	and ammonium-salts = 172 lb. nitrogen 13 years, 1852-64. Unmanured 19 years, 1865-83	more or less than Plot 5	more or less than Plot 7	more or less than Plot 8
	Plot 5	Plot 7	Plot 8	Plot 16			
	bushels	bushels	bushels	bushels	bushels	bushels	bushels
13 years, 1852-64	18⅜	37⅛	39	39½	+ 21⅛	+ 2⅜	+ 0⅛
19 „ 1865-83	13⅛	29¼	34⅜	14⅛	+ 1½	−15⅛	−19¾

Before referring to the figures, it may be stated that in 1863, which was the year of the highest yield of wheat during the whole course of our experiments, the three plots (7, 8, and 16) receiving the different amounts of ammonium-salts, yielded respectively, 53⅝, 55¾, and 55⅞ bushels of wheat; whilst in 1864, which was also a very favourable year for wheat, they yielded 45¾, 49⅞, and 51⅛ bushels. That is, the plot receiving the highest amount of ammonium-salts yielded, even in the most favourable seasons, scarcely any more than Plot 8 with 200 lb. less annually applied. Then, as the Table shows, the average yield over the thirteen years of the application of the very excessive amount of ammonium-salts to Plot 16 was only half a bushel more than on Plot 8 with 200 lb. less; and only 2⅜ bushels less than on Plot 7 with 400 lb. less annually applied. Under these circumstances, it was decided to stop the application altogether on Plot 16 with the highest amount of ammonium-salts, and to take a series of crops without any manure, to test

the productive effects of any residue that there might be, and the experiment was so continued for nineteen years.

Details not given in the Table show, that in the first year after the cessation of the application of ammonium-salts to Plot 16, it yielded 32⅜ bushels of wheat, against 43⅝ on Plot 8, and 40¼ on Plot 7, where the respective amounts of ammonium-salts were still applied. After that, however, there was a very marked decline on Plot 16, giving, as the table shows, an average produce of only 14⅝ bushels over the 19 years without manure, against an average of 39½ bushels over the preceding 13 years of the annual application of the manure. It is further seen that over the 19 years the residue gave an average of only 1½ bushel more than Plot 5 with the mineral manure without nitrogen (the produce of which had itself declined more than this over the 19 years); whilst it gave 15½ bushels less than Plot 7, with 400 lb. of ammonium-salts still annually applied, and 19¾ bushels less than Plot 8 with the continued application of 600 lb. of ammonium-salts.

There is, in fact, abundant evidence to show, that there is but little effective *manure residue* after the growth of a grain crop by the application of ammonium-salts; and there is little doubt that the produce of 1½ bushel of grain, and its straw, per acre per annum more over the 19 years after the cessation of the application of ammonium-salts, than on Plot 5 with the mineral manure alone is, so far as it is to be attributed to residue, mainly due to the increased *crop residue*, stubble and roots, accumulated during the 13 years of the application. And much the same may be said of the after effects when grain crops have been grown by the aid of nitrate of soda.

In contrast with the foregoing results showing that there is practically little or no effective manure residue when ammonium-salts have been applied and a grain crop grown, we have now to adduce results showing the persistent, though it is true comparatively slow, effect of residues of phosphoric acid, and of potash, previously applied. The results given in the next Table (VI., p. 18) illustrate the point.

The two plots, 10*a* and 10*b*, have grown wheat from 1844 up to the present time. For the crop of 1844 they each received a mineral manure containing potash and superphosphate. In each of the next seven years, to 1851 inclusive, 10*a* received ammonium-salts alone. During the same seven years 10*b* twice received mineral manure containing potash, soda, magnesia, and superphosphate, and five times ammonium-salts. In other words, during the first eight years to 1851

inclusive, 10*b* twice received potash and phosphoric acid when 10*a* did not. From 1852 up to the present time, each of the two plots has received exactly the same manure, namely, 400 lb. of ammonium-salts per acre per annum. The Table shows the average produce of dressed grain per acre per annum on each of the two plots, over each of the four 10-yearly periods, and over the 40 years, 1852-91.

TABLE VI.—*Experiments on Wheat, with Artificial Manures.*

	Ammonium-salts alone = 86 lb. nitrogen each year 1852–91		
	Previously—Mineral manure once (1844); ammonium-salts 7 times	Previously—Mineral manure 3 times (1844, '48, and '50); Ammonium-salts 5 times	10*b* more than 10*a*
	Plot 10*a*	Plot 10*b*	
	bushels	bushels	bushels
10 years, 1852–61	20 1/8	25 1/2	4 3/8
„ 1862–71	24 1/8	26 3/8	2 1/4
„ 1872–81	16 1/2	18 1/8	1 5/8
„ 1882–91	18 7/8	19 3/4	0 7/8
40 „ 1852–91	20 1/8	22 1/2	2 3/8

It is seen that, over each of the four 10-yearly periods, 10*b*, which had previously received potash and phosphoric acid twice more than 10*a* during the eight years prior to the commencement of the experiment, gave also more produce of grain than 10*a*; the excess diminishing, however, from period to period. As the last column shows, there was an average annual excess over the first ten years of the effect of the residue of potash and phosphoric acid, of 4 3/8 bushels, over the second ten years of 2 1/4 bushels, over the third of 1 5/8 bushel, and over the fourth of only 7/8 bushel; or, taking the average of the forty years, there was an excess on 10*b*, with the greater residue of potash and phosphoric acid previously applied, of 2 3/8 bushels per acre per annum more than on 10*a*. It happens that we have the analyses of the ashes of the crops over each of these 10-yearly periods, and the results show that over each there was more of both potash and phosphoric acid in the crops of 10*b* than in those of 10*a*, the excess diminishing from period to period. Over the forty years, however, the total produce per acre (grain and straw) of 10*b* contained 108 lb. more potash, and 69·5 lb. more phosphoric acid, than that of 10*a*.

There can be no doubt, therefore, that the extra potash and phosphoric acid applied on 10*b* prior to the period of forty years

to which the results in the Table refer, had a distinct influence both on the amounts of potash and phosphoric acid taken up in the crops, and with this on the amount of produce over the succeeding forty years. Further, the effect of the residue diminished from period to period; whilst calculations show that, over the forty years, much less than the total excess of potash and phosphoric acid applied on 10*b* had been taken up. The evidence is, therefore, clear, that in the case of some soils the at first unrecovered residue of both potash and phosphoric acid becomes partially and slowly available for future crops for many years.

So far as potash is concerned, the results next to be quoted afford striking evidence on the point. During the eight years preceding the period of forty to which the results in the Table (VII., p. 20) relate, the four plots, Nos. 11, 12, 13, and 14, in the experimental wheat-field were manured as follows. Each received an abundance of superphosphate, representing in round numbers about 500 lb. of phosphoric acid over the eight years; also a considerable amount of ammonium-salts, some rape-cake, and two of them a little guano. No. 11, however, received neither potash (except a little in rape-cake), soda, nor magnesia; No. 12, 587 lb. of potash, and some soda and magnesia; No. 13, 737 lb. of potash, and a little magnesia; and No. 14, 566 lb. of potash, some soda, and some magnesia. There would, therefore, be a considerable residue of phosphoric acid on each of the four Plots, and of potash on Plots 12, 13, and 14. With the plots in this condition as to residue of phosphoric acid and potash from previous applications, they were manured in each of the succeeding forty years, from 1852 to 1891 inclusive, as follows. Each received the same amount of superphosphate, and the same amount of ammonium-salts, every year. Plot 11 received neither potash, soda, nor magnesia, Plot 12 received sulphate of soda, Plot 13 sulphate of potash, and Plot 14 sulphate of magnesia, in addition, every year.

The Table (VII.) shows the average annual produce of grain, on each of the four plots, over each of the four ten yearly periods, and over the forty years; also the average annual produce of straw over the forty years.

Looking to the right-hand division of the table, it is seen that, over the forty years, Plot 12, with a considerable residue of potash from previous years, gave an increase over Plot 11 without any potash supply, of $5\frac{5}{8}$ bushels of grain, and $5\frac{1}{2}$ cwt. of straw, per acre per annum; and Plot 14, also with a large residue of potash, gave an average annual increase over Plot 11, of $6\frac{1}{4}$ bushels of grain, and $6\frac{3}{8}$ cwt. of straw. Plot 13, however, with both residue and direct supply of potash, gave an increase

over Plot 11, of 6⅝ bushels of grain, and 8 cwt. of straw, per acre per annum. It should be added that the crops on Plot 11, with the great deficiency of potash, showed more and more an unhealthy condition, especially in unfavourable seasons; and the grain gave, over each period, a lower weight per bushel than on either Plots 12 or 14, and lower still than on Plot 13, which over each period gave the highest weight.

TABLE VII.—*Experiments on Wheat, with Artificial Manures.*

	Ammonium-salts = 86 lb. nitrogen, and superphosphate				More than Plot 11 without potash		
		with residue of potash					
	alone	and sulphate of soda	and sulphate of potash	and sulphate of magnesia	with residue of potash	with residue, and direct supply, of potash	with residue of potash
	Plot 11	Plot 12	Plot 13	Plot 14	Plot 12	Plot 13	Plot 14
DRESSED GRAIN.							
	bushels	bushels	bushels	bushels	bushels	bushels	bushels
10 years, 1852–61	28⅜	33⅜	32⅞	33½	5⅛	4⅝	5⅛
„ 1862–71	27⅞	34¼	34⅜	34⅜	6⅜	6¼	6¼
„ 1872–81	21⅜	25	26¾	26½	3¼	5	4⅜
„ 1882–91	22¼	30	32½	31⅛	7¼	9¾	8⅜
40 „ 1852–91	25⅛	30¾	31¾	31⅜	5⅜	6⅝	6¼
STRAW.							
	cwt.	cwt.	cwt.	cwt.	cwt.	cwt.	cwt.
40 years, 1852–91	23¾	29¼	31¾	30⅛	5½	8	6⅜

That the result, both as to quantity and quality of produce, was directly connected with the amount of potash available within the soil, and not with that of the soda on Plot 12, or of the magnesia on Plot 14, is evident from the following facts. The amount of soda in the forty years' crops (grain and straw) was considerably less in those of Plot 12 with soda annually supplied, than in those of Plot 11 with none supplied; and the amount of magnesia in the crops of Plot 14 with magnesia supplied, was only 55 lb. more over the forty years than in those of Plot 11 with none supplied—the excess approximately corresponding to the increase of crop. On the other hand, the amounts of potash found in the crops of the forty years, were 466 lb. more on Plot 12, and 538 lb. more on Plot 14, each with residue of potash, than on Plot 11 without either residue or direct supply of potash; whilst the crops of Plot 13, with both residue and direct supply of potash, and the best condition of the crops, contained 1,065 lb. more potash than those of Plot 11.

Inasmuch, however, as the Rothamsted soil and subsoil contain an enormous quantity of potash, of which a certain amount is annually liberated in an available condition, and the quantity of this is influenced in some, but an unknown degree, by the action of the other saline matters supplied in the manures, it would be unsafe to say that exactly the amount of the excess taken up on Plots 12 and 14, compared with Plot 11, was attributable to residue, and none at all to natural soil resources.

It may be considered established, that when phosphates or potash are applied to such a soil, little if any phosphoric acid, and not much potash, will be lost by drainage, and that the residue left after the growth of a crop will in great part remain; and although in a less rapidly available condition than a fresh supply would be, some of it will become gradually available to succeeding crops, and so at any rate serve to prevent exhaustion. Its value will, however, obviously be much less than that of an equal amount freshly applied.

The evidence adduced in the various foregoing illustrations shows, that very large crops can be grown by means of artificial manures containing ammonium-salts or nitrate of soda, with phosphoric acid and potash, without organic matter, but that so far as the nitrogen of the manures is concerned, and especially when such manures are applied for grain crops, there is but little accumulation in the soil for future crops, there being frequently very considerable loss as nitrates by drainage. Then as to the phosphoric acid and potash of artificial manures, they are not subject to material loss by drainage, as is the nitrogen; but they enter into more or less fixed combinations within the soil, from which they are only very slowly liberated in a condition of solubility available for growing crops. When, however, crops are grown by means of purchased dung, or by the consumption of cake, corn, &c., by stock, there will be "cumulative fertility," for which there would be claim for compensation; and farmers, who know that when land has been unduly exhausted it cannot be got into condition again under several years, and that when it is in good condition it will yield good crops for several years, look to the Legislature to protect their interests.

The Valuation of Unexhausted Manures.

Our last paper on this subject was published in this Journal in 1885. Since that time, there have been great changes in the value both of articles used as food for stock, and of the various constituents upon which the value of artificial manures

depends. Our tables have, therefore, now lost much of their applicability, and we have frequently been asked to adapt them to the present scale of prices; and, as questions of compensation are sure to become matters of importance before long, we are glad to take the opportunity of reconsidering our valuations.

The first Table, now numbered VIII. (p. 24), which gives the "*Average Composition, per Cent. and per Ton, of Cattle Foods*" is not altered. The second Table (IX., pp. 28–29), "*Showing the Data, the Method, and the Results of the Estimation of the Original Manure-value of Cattle Foods after Consumption,*" is, however, very materially altered so far as the money valuations are concerned. These are now reduced by about one-third, as will be further explained presently. The third Table (X., p. 33) is altered throughout, in accordance with the altered total or original manure-value as given in the second Table (IX.); and the table on p. 35, which gives an illustration of the application of the valuations, is also altered, in accordance with the new rates of value. To render the Tables easily intelligible, and the more convenient for reference and use, the description and discussion of them as given in our previous paper is now substantially reproduced, but with such alterations or corrections as the changes in them indicate to be necessary. For any further details, we must refer to the earlier papers themselves, published in this Journal in 1875, and in 1885, especially the latter.

The existence of *unexhausted fertility*, resulting from the consumption of cattle foods, depends upon the fact that when organic matter, animal or vegetable, is applied to the soil as manure, its complete decay, and the complete liberation of its fertilising constituents, extend over a considerable period of time. Poor land cannot be suddenly brought into "*condition*" by the consumption on the farm of purchased foods. Nor can "*condition*"—that is, accumulated fertility—be at once withdrawn by suddenly stopping the use of the foods.

As has been shown, the Rothamsted field experiments afford numerous illustrations of such gradual accumulation, and only gradual exhaustion. It has been seen that it may take a great many years of unmanured cropping to exhaust the accumulation from a few years' application of dung, and to bring the land back to its original state. Even when rape cake is applied for the continuous growth of corn crops, a considerable unexhausted residue remains in the soil. The fact that such accumulation does take place cannot be disputed. But when we come to consider—of what the accumulation consists, what is its amount,

and what its money value, the real difficulties of the problem to be solved become apparent.

Each individual food, when judiciously used in conjunction with others, contributes more or less to the increase of the animal consuming it; and the increase will carry away a certain amount of the constituents of the food. The remainder, which constitute the manure, will, in the first place, increase the produce of the crops to which it is applied; but it will also leave an unexhausted residue, the amount and the money value of which to the succeeding tenant we have to endeavour to determine.

We must, then, in the first place, form an estimate of the amount of increase in live weight of animals which a given quantity of each food will produce, and of the amount of manure constituents which that increase will take from the food. Next, we must endeavour to estimate the increase in the crops, and the amount of constituents so removed. Lastly, the amount, and the value, of the manure residue has to be estimated. This we have done in the case of a number of the foods, the composition, the original manure value, and the unexhausted manure value of which are given in the Tables which follow. We have also decided upon a scale of reduction of the unexhausted manure value from year to year, and in this way arrived at an estimate of the money value of the residue accumulated over a period of eight years. Finally, having thus come to a conclusion as to the amount of what may be called the *compensation value* of the accumulated residue, we have devised a simple method of calculation, starting from the *total*, or *original manure value*, of the various foods—that is, from the value deducting the constituents in the increase in live weight only, and reckoning the remainder at the prices at which they can be purchased in artificial manures.

Average Composition of Cattle Foods.

Table VIII., p. 25, shows the average composition, per cent. and per ton, of thirty-six different foods, so far as this is necessary for the purpose of manure-value calculations; that is, it gives the amounts *per cent.* of dry matter, nitrogen, total mineral matter (ash), phosphoric acid, and potash, and the amount *per ton* of the foods, of nitrogen, phosphoric acid, and potash. In some cases the figures are the same as in our original Table, published in 1861; but, for the purposes of our paper—"On the Valuation of Unexhausted Manures"—published in this Journal in 1885, more recent analyses were in all cases had recourse to, and alterations were made if it seemed desirable. For the present paper (1897), the figures as to the

TABLE VIII.—*Average Composition, Per Cent. and Per Ton, of Cattle Foods.*

Foods	Per cent.					Per ton		
	Dry matter	Nitrogen	Mineral matter (ash)	Phosphoric acid	Potash	Nitrogen	Phosphoric acid	Potash
	per cent.	per cent.	per cent.	per cent.	per cent.	lb.	lb.	lb.
1. Linseed	90·00	3·60	4·00	1·54	1·37	80·64	34·50	30·69
2. Linseed cake	88·50	4·75	6·50	2·00	1·40	106·40	44·80	31·36
3. Decorticated cotton cake	90·00	6·60	7·00	3·10	2·00	147·84	69·44	44·80
4. Palm-nut cake	91·00	2·50	3·60	1·20	0·50	56·00	26·88	11·20
5. Undecorticated cotton cake	87·00	3·75	6·00	2·00	2·00	84·00	44·80	44·80
6. Cocoa-nut cake	90·00	3·40	6·00	1·40	2·00	76·16	31·36	44·80
7. Rape cake	89·00	4·90	7·50	2·50	1·50	109·76	56·00	33·60
8. Peas	85·00	3·60	2·50	0·85	0·96	80·64	19·04	21·50
9. Beans	85·00	4·00	3·00	1·10	1·30	89·60	24·64	29·12
10. Lentils	88·00	4·20	4·00	0·75	0·70	94·08	16·80	15·68
11. Tares (seed)	84·00	4·20	2·50	0·80	0·80	94·08	17·92	17·92
12. Indian corn	88·00	1·70	1·40	0·60	0·37	38·08	13·44	8·29
13. Wheat	85·00	1·80	1·70	0·85	0·53	40·32	19·04	11·87
14. Malt	94·00	1·70	2·50	0·80	0·50	38·08	17·92	11·20
15. Barley	84·00	1·65	2·20	0·75	0·55	36·96	16·80	12·32
16. Oats	86·00	2·00	2·80	0·60	0·50	44·80	13·44	11·20
17. Rice meal[1]	90·00	1·90	7·50	(0·60)	(0·37)	42·56	(13·44)	(8·29)
18. Locust beans[1]	85·00	1·20	2·50	—	—	26·88	—	—
19. Malt coombs	90·00	3·90	8·00	2·00	2·00	87·36	44·80	44·80
20. Fine pollard	86·00	2·45	5·50	2·90	1·46	54·88	64·96	32·70
21. Coarse pollard	86·00	2·50	6·40	3·50	1·50	56·00	78·40	33·60
22. Bran	86·00	2·50	6·50	3·60	1·45	56·00	80·64	32·48
23. Clover hay	83·00	2·40	7·00	0·57	1·50	53·76	12·77	33·60
24. Meadow hay	84·00	1·50	6·50	0·40	1·60	33·60	8·96	35·84
25. Pea straw	82·50	1·00	5·50	0·35	1·00	22·40	7·84	22·40
26. Oat straw	83·00	0·50	5·50	0·24	1·00	11·20	5·38	22·40
27. Wheat straw	84·00	0·45	5·00	0·24	0·80	10·08	5·38	17·92
28. Barley straw	85·00	0·40	4·50	0·18	1·00	8·96	4·03	22·40
29. Bean straw	82·50	0·90	5·00	0·30	1·00	20·16	6·72	22·40
30. Potatoes	25·00	0·25	1·00	0·15	0·55	5·60	3·36	12·32
31. Carrots	14·00	0·20	0·90	0·09	0·28	4·48	2·02	6·27
32. Parsnips	16·00	0·22	1·00	0·19	0·36	4·93	4·26	8·06
33. Mangel wurzels	12·50	0·22	1·00	0·07	0·40	4·93	1·57	8·96
34. Swedish turnips	11·00	0·25	0·60	0·06	0 22	5·60	1·34	4·93
35. Yellow turnips[1]	9·00	0·20	0·65	(0·06)	(0·22)	4·48	(1·34)	(4·93)
36. White turnips	8·00	0·18	0·68	0·05	0·30	4·03	1·12	6·72

[1] In the case of neither Rice Meal, Locust Beans, nor Yellow Turnips, have records of ash analyses been found. For Rice Meal the same percentages of phosphoric acid and potash as in Indian Corn, and for Yellow Turnips the same as in Swedes, are provisionally adopted; but in all the Tables the assumed results are given in parentheses. For Locust Beans no figure has been assumed, and the columns are left blank.

composition of the foods, which were carefully settled in 1885, are now again adopted.

Although the figures given in the Table (VIII., p. 24) may be taken as fairly indicating the *average* composition of the different foods, yet it must be understood that in the case of almost every one of the articles in the list, individual samples may vary even considerably from the average. In the case of foods which are manufactured, or imported, the percentage of dry matter is usually high. In the case of those which may be either imported or home-grown, the variations in the percentage of dry matter in different samples may be comparatively wide; it being, as a rule, distinctly higher in the imported articles, which could not be shipped unless in a drier condition than is usual with the home-grown product. In such cases, therefore, the imported food will probably contain a higher, or the home-grown one a lower, percentage of dry matter than the average amount given in the Table. Even in the case of professedly ripened products, such as cereal grains and leguminous seeds, the character of the season will materially influence their condition of dryness; and the same remark applies, in a greater or less degree, to such products as hays and straws. Succulent matters, again, such as roots, vary very considerably according to season, and to condition of maturity.

So far as individual constituents are concerned, very similar reservations must be made; and especially is this so in the case of the nitrogen. Even with professedly ripened products the percentage of nitrogen may vary considerably, according to soil, manuring, climate, or season, &c., but especially according to season; and this is the case in a less degree with the phosphoric acid, and the potash, of such articles. But in the case of imperfectly ripened products, such as hay, and in a much greater degree in that of still less evenly matured and more succulent ones, such as roots, the percentage of nitrogen may vary very materially, and that of the phosphoric acid and potash to some extent.

Whilst, therefore, the figures given in the Table may be taken as representing the fairly average composition of the different foods, they must be adopted or modified with judgment, having regard to the influence of the conditions of growth, maturity, preparation, or preservation, to which they have been subject. Fortunately, however, unless the variation from the standard composition adopted in the Table be considerable—indeed, more than is usual—the effect on the estimates of manure value will not be material; but it will obviously be much greater in the case of the nitrogen than in that of either the phosphoric acid or the potash.

Total or Original Manure-value of Consumed Cattle Foods.

Table IX. (pp. 28–29) shows the method, and the results, of the calculation of the *total* or *original manure value* of the different foods, adopting as a basis their composition as given in Table VIII.

The first column of the Table (IX.) shows the estimated amounts of each food required to give one part of fattening increase in live-weight of oxen or sheep; and the second column shows the amounts of such increase that would, accordingly, be yielded by the consumption of one ton of each food. It is obvious that some estimate of this kind must be made before we can reckon how much of the manure constituents of the food are carried off by the animal-increase, and consequently how much remain for manure. These columns may, however, be very seriously misleading, unless their real meaning be understood. Thus, if given without further explanation, it might be concluded that, by the consumption by oxen or sheep of one ton of any one of the different foods used alone, the amount of fattening increase given in the second column of the Table would be produced. In other words, that, if so given, a ton of linseed cake would yield 373 lb., a ton of oat straw 124 lb., or a ton of swedes 20½ lb. of increase. What is meant is, that when any one of the foods is given in the judicious amount, and admixture with other foods, which experience shows to be beneficial, it may be estimated that one ton of the food so consumed will, approximately, contribute the amount of increase in live-weight stated.

This will be better understood by giving some explanation of the way in which the figures have been arrived at. In the case of a few typical foods, a number of feeding experiments were selected in which the mixtures given were comparatively simple, and the results fairly average; and the productive effect of the particular food has been calculated, by eliminating that of the associated food, or foods, as determined in the case of other experiments, the results of which have been calculated in the same way. For example, the quantity of clover chaff required to produce one of increase in various experiments was determined as follows:—

	Clover chaff to 1 increase
Oxen—with Linseed Cake, Barley, Swedes, and Clover Chaff	13·0
Oxen— " " " "	14·3
Sheep—with Linseed Cake, Swedes, and Clover Chaff	14·7
Sheep—with Barley, Swedes, and Clover Chaff	13·4
Sheep— " " " "	15·5
Mean	14·2

In a similar manner the productive effects of linseed, linseed cake, barley, beans, and swedes, each used in suitable admixture with other foods, have been estimated. Thus the actual and comparative productive effects of a few characteristic foods have been approximately determined; and from these results the capacity of allied foods has been estimated, taking into consideration the relative amounts of digestible and indigestible constituents which the foods to be compared on the average contain. It is in this way that the figures in the first and second columns of Table IX. have been arrived at. It should be stated, however, that in the case of the straws no direct experimental data were at command, and their productive effects are estimated mainly on their recorded amounts of digestible constituents compared with those in hay, and they are more probably given too high than too low.

It is obvious that such estimates can be only approximately correct; but they are at any rate the best that existing knowledge renders it possible to make. It is pretty certain that the amounts of increase assumed to be produced are higher than those usually obtained. The amount estimated to be yielded by linseed cake, for example, is certainly higher than would be obtained when, as is sometimes the case, it is given in such excessive amount that much is voided by the animals undigested. On the other hand, the amounts of the different foods estimated to be required to give 1 part of increase are doubtless higher than would be so required, if as large a proportion of the constituents were digested and utilised as has been shown to be digestible in the German experiments on that subject. In those experiments the animals were for the most part kept on mere sustenance food, so that they would digest the maximum proportion of the constituents they received. In the case of fattening, however, especially with early maturity, the conditions are very different. The animal receives a greater or less excess of food, and not only voids proportionally more undigested, but may transform more than is fully utilised. It is, nevertheless, economy to give an excess within certain limits. The apparent waste is, in fact, more than counterbalanced. Thus, in the first place, the manure value of the not utilised food still remains intact; but the real source of the economy is in the shortening of the time of feeding, and so, at the cost of some excess of food, saving the amount that would be expended in the mere sustenance of the animal in feeding for a longer period.

Trusting that, with these explanations, the figures will not be misunderstood, we may proceed to the consideration of the

TABLE IX.—*Showing the Data, the Method, and the Results, of the Estimation*

Nos.	Description of food	Fattening increase in live weight (oxen or sheep)		Nitrogen						
				In food		In fattening increase (at 1·27 per cent.)		In manure		
		Food to 1 increase	Increase per ton of food	Per cent.	Per ton	From 1 ton of food	Per cent. of total consumed	Total remaining for manure	Nitrogen equal ammonia	Value of ammonia at 4*d.* per lb.
			lb.	per cent.	lb.	lb.	per cent.	lb.	lb.	£ s. d.
1	Linseed	5·0	448·0	3·60	80·64	5·69	7·06	74·95	91·0	1 10 4
2	Linseed cake	6·0	373·3	4·75	106·40	4·74	4·45	101·66	123·4	2 1 2
3	Decorticated cotton cake	6·5	344·6	6·60	147·84	4·38	2·96	143·46	174·2	2 18 1
4	Palm-nut cake	7·0	320·0	2·50	56·00	4·06	7·25	51·94	63·1	1 1 0
5	Undecorticated cotton cake	8·0	280·0	3·75	84·00	3·56	4·24	80·44	97·7	1 12 7
6	Cocoa-nut cake	8·0	280·0	3·40	76·16	3·56	4·67	72·60	88·2	1 9 5
7	Rape cake	(10)	(224)	4·90	109·76	2·84	2·59	106·92	129·8	2 3 3
8	Peas	7·0	320·0	3·60	80·64	4·06	5·03	76·58	93·0	1 11 0
9	Beans	7·0	320·0	4·00	89·60	4·06	4·53	85·54	103·9	1 14 8
10	Lentils	7·0	320·0	4·20	94·08	4·06	4·32	90·02	109·3	1 16 5
11	Tares (seed)	7·0	320·0	4·20	94·08	4·06	4·32	90·02	109·3	1 16 5
12	Indian corn	7·2	311·1	1·70	38·08	3·95	10·37	34·13	41·4	0 13 10
13	Wheat	7·2	311·1	1·80	40·32	3·95	9·80	36·37	44·2	0 14 9
14	Malt	7·0	320·0	1·70	38·08	4·06	10·66	34·02	41·3	0 13 9
15	Barley	7·2	311·1	1·65	36·96	3·95	10·69	33·01	40·1	0 13 4
16	Oats	7·5	298·7	2·00	44·80	3·79	8·46	41·01	49·8	0 16 7
17	Rice meal	7·5	298·7	1·90	42·56	3·79	8·91	38·77	47·1	0 15 8
18	Locust beans	9·0	248·9	1·20	26·88	3·16	11·76	23·72	28·8	0 9 7
19	Malt coombs	8·0	280·0	3·90	87·36	3·56	4·08	83·80	101·8	1 13 11
20	Fine pollard	7·5	298·7	2·45	54·88	3·79	6·91	51·09	62·0	1 0 8
21	Coarse pollard	8·0	280·0	2·50	56·00	3·56	6·35	52·44	63·7	1 1 3
22	Bran	9·0	248·9	2·50	56·00	3·16	5·64	52·84	64·2	1 1 5
23	Clover hay	14·0	160·0	2·40	53·76	2·03	3·78	51·73	62·8	1 0 11
24	Meadow hay	15·0	149·3	1·50	33·60	1·90	5·65	31·70	38·5	0 12 10
25	Pea straw	16·0	140·0	1·00	22·40	1·78	7·95	20·62	25·0	0 8 4
26	Oat straw	18·0	124·4	0·50	11·20	1·58	14·11	9·62	11·7	0 3 11
27	Wheat straw	21·0	106·7	0·45	10·08	1·36	13·49	8·72	10·6	0 3 6
28	Barley straw	23·0	97·4	0·40	8·96	1·24	13·84	7·72	9·4	0 3 2
29	Bean straw	22·0	101·8	0·90	20·16	1·29	6·39	18·87	22·9	0 7 8
30	Potatoes	60·0	37·3	0·25	5·60	0·47	8·39	5·13	6·2	0 2 1
31	Carrots	85·7	26·1	0·20	4·48	0·33	7·37	4·15	5·0	0 1 8
32	Parsnips	75·0	29·9	0·22	4·93	0·38	7·71	4·55	5·5	0 1 10
33	Mangel wurzels	96·0	23·3	0·22	4·93	0·30	6·09	4·63	5·6	0 1 10
34	Swedish turnips	109·1	20·5	0·25	5·60	0·26	4·64	5·34	6·5	0 2 2
35	Yellow turnips	133·3	16·8	0·20	4·48	0·21	4·69	4·27	5·2	0 1 9
36	White turnips	150·0	14·9	0·18	4·03	0·19	4·71	3·84	4·7	0 1 7

of the Original Manure Value of Cattle Foods after Consumption.

Phosphoric Acid						Potash						Total or original manure value per ton of food consumed
In food		In fattening increase (at 0·86 per cent.)		In manure		In food		In fattening increase (at 0·11 per cent.)		In manure		
Per cent.	Per ton	From 1 ton of food	Per cent. of total consumed	Total remaining for manure	Value at 2d. per lb.	Per cent.	Per ton	From 1 ton of food	Per cent. of total consumed	Total remaining for manure	Value at 1½d. per lb.	
per cent.	lb.	lb.	per cent.	lb.	s. d.	per cent.	lb.	lb.	per cent.	lb.	s. d.	£ s. d.
1·54	34·50	3·85	11·16	30·65	5 1	1·37	30·69	0·49	1·60	30·20	3 9	1 19 2
2·00	44·80	3·21	7·17	41·59	6 11	1·40	31·36	0·41	1·31	30·95	3 10	2 11 11
3·10	69·44	2·96	4·26	66·48	11 1	2·00	44·80	0·38	0·85	44·42	5 7	3 14 9
1·20	26·88	2·75	10·23	24·13	4 0	0·50	11·20	0·35	3·13	10·85	1 4	1 6 4
2·00	44·80	2·41	5·38	42·39	7 1	2·00	44·80	0·31	0·69	44·49	5 7	2 5 3
1·40	31·36	2·41	7·68	28·95	4 10	2·00	44·80	0·31	0·69	44·49	5 7	1 19 10
2·50	56·00	1·93	3·45	54·07	9 0	1·50	33·60	0·25	0·74	33·35	4 2	2 16 5
0·85	19·04	2·75	14·44	16·29	2 9	0·96	21·50	0·35	1·63	21·15	2 8	1 16 5
1·10	24·64	2·75	11·16	21·89	3 8	1·30	29·12	0·35	1·20	28·77	3 7	2 1 11
0·75	16·80	2·75	16·37	14·05	2 4	0·70	15·68	0·35	2·23	15·33	1 11	2 0 8
0·80	17·92	2·75	15·35	15·17	2 6	0·80	17·92	0·35	1·95	17·57	2 2	2 1 1
0·60	13·44	2·68	19·94	10·76	1 9	0·37	8·29	0·34	4·10	7·95	1 0	0 16 7
0·85	19·04	2·68	14·08	16·36	2 9	0·53	11·87	0·34	2·86	11·53	1 5	0 18 11
0·80	17·92	2·75	15·35	15·17	2 6	0·50	11·20	0·35	3·13	10·85	1 4	0 17 7
0·75	16·80	2·68	15·95	14·12	2 4	0·55	12·32	0·34	2·76	11·98	1 6	0 17 2
0·60	13·44	2·57	19·12	10·87	1 10	0·50	11·20	0·33	2·94	10·87	1 4	0 19 9
(0·60)	(13·44)	2·57	(19·12)	(10·87)	(1 10)	(0·37)	(8·29)	0·33	(4·00)	(7·96)	(1 0)	(0 18 6)
—	—	2·14	—	—	—	—	—	0·27	—	—	—	—
2·00	44·80	2·41	5·38	42·39	7 1	2·00	44·80	0·31	0·69	44·49	5 7	2 6 7
2·90	64·96	2·57	3·96	62·39	10 5	1·46	32·70	0·33	1·01	32·37	4 1	1 15 2
3·50	78·40	2·41	3·07	75·99	12 8	1·50	33·60	0·31	0·92	33·29	4 2	1 18 1
3·60	80·64	2·14	2·65	78·50	13 1	1·45	32·48	0·27	0·83	32·21	4 0	1 18 6
0·57	12·77	1·38	10·81	11·39	1 11	1·50	33·60	0·18	0·54	33·42	4 2	1 7 0
0·40	8·96	1·28	14·28	7·68	1 3	1·60	35·84	0·16	0·45	35·68	4 6	0 18 7
0·35	7·84	1·20	15·31	6·64	1 1	1·00	22·40	0·15	0·67	22·25	2 9	0 12 2
0·24	5·38	1·07	19·89	4·31	0 9	1·00	22·40	0·14	0·63	22·26	2 9	0 7 5
0·24	5·38	0·92	17·10	4·46	0 9	0·80	17·92	0·12	0·67	17·80	2 3	0 6 6
0·18	4·03	0·84	20·84	3 19	0 6	1·00	22·40	0·11	0·49	22·29	2 9	0 6 5
0·30	6·72	0·88	13·10	5·84	1 0	1·00	22·40	0·11	0·49	22·29	2 9	0 11 5
0·15	3·36	0·32	9·52	3·04	0 6	0·55	12·32	0·04	0·32	12·28	1 6	0 4 1
0·09	2·02	0·22	10·89	1·80	0 4	0 28	6·27	0·03	0·48	6·24	0 9	0 2 9
0·19	4·26	0·26	6·10	4·00	0 8	0·36	8·06	0·03	0·37	8·03	1 0	0 3 6
0·07	1·57	0·20	12·74	1·37	0 3	0·40	8·96	0·03	0·34	8·93	1 1	0 3 2
0·06	1·34	0·18	13·43	1·16	0 2	0·22	4·93	0·02	0·41	4·91	0 7	0 2 11
(0·06)	(1·34)	0·14	(10·78)	(1·20)	(0 2)	(0·22)	(4·93)	0·02	(0·34)	(4·91)	(0 7)	(0 2 6)
0·05	1·12	0·13	11·61	0·99	0 2	0·30	6·72	0·02	0·30	6·70	0 10	0 2 7

rest of the Table, only further remarking, in regard to the estimates in question, that the amount of the manure constituents of the food carried off by fattening increase is under all circumstances so small that, for the purposes of our calculations of manure value, even a considerable variation from the average amounts assumed to be taken up by the animal would affect the final result but little.

The next division of the Table (IX., pp. 28–29), comprising seven columns, relates to the amount, and to the distribution, of the nitrogen of the foods. There are given—the amounts of it per cent., and per ton, as in Table VIII. (p. 24); the actual amount estimated to be contained in the increase in live weight of the animal consuming one ton of the food, and the percentage of the total nitrogen consumed which is so retained in the increase; the amount of the nitrogen of the food remaining for manure, the amount of ammonia to which it corresponds, and its money value, now reckoned at only 4*d.* per lb. of ammonia; instead of 8*d.*, as in 1875, and 6*d.*, as in 1885.

Throughout the calculations we have assumed only fattening increase to be produced, and that this will contain 8 per cent. of nitrogenous substance, corresponding to 1·27 per cent. of nitrogen in the increase. It will be seen that, according to the figures, the only food in the list of which a ton is estimated to contribute more than 5 lb. of nitrogen to the fattening increase is linseed, and that in the case of none of the cakes, or of the leguminous seeds, will 1 ton contribute 5 lb. of nitrogen to the increase, whilst the amount is in several cases under 4 lb. A ton of the cereal grains, or of their products (and locust beans), generally contributes under 4 lb.; a ton of hay or straw less than half as much; and a ton of roots very much less still.

To put it in another way: of the total nitrogen consumed in the foods rich in that substance, such as the cakes and the leguminous seeds, there is generally less than 5 per cent. retained in the fattening increase in live-weight. The cereal grains, on the other hand, which are much less rich in nitrogen, contribute a much larger proportion of their total amount to the increase; indeed, generally about 10 per cent. of it. The gramineous straws contribute a higher proportion still, whilst roots (mangels and turnips) lose by feeding on an average only about 5 or 6 per cent. of their nitrogen.

It is thus seen that, when fattening increase only is produced, the proportion of the nitrogen of the food which is retained by the animal, and so lost to the manure, is very small in the case of the richer foods, but more in that of the poorer

ones; but even with them it seldom exceeds 10 per cent., excepting with the straws. It may be assumed, however, that when the foods are consumed by store animals, about twice as much of the nitrogen of the food is retained by the animal, and so lost to the manure. And when, as is more and more the case with early maturity, the increase comprises a larger proportion of growth than in mere fattening, the amount of the nitrogen of the food which will be lost to the manure will be between that given in the Table and twice as much.

The third division of the Table relates to the phosphoric acid, and there are given for each food, as in the case of the nitrogen, the amounts of it per cent. and per ton of the foods; the amount estimated to be retained in the increase; the amount remaining for manure, and the money value of this at 2*d.* per lb.; instead of 2¼*d.*, as adopted in 1875, and 3*d.* in 1885.

It will be seen that there is only about two-thirds as much phosphoric acid as of nitrogen retained in a given weight of fattening increase; but, owing to the very generally less, and sometimes much less, amount of it in the foods, a greater proportion of that consumed is retained in the animal, and a less proportion remains for manure. It should be added that, in the case of store and still growing animals, the amount of phosphoric acid retained in a given weight of increase will be very much greater than in mere fattening; indeed, in mere store increase it may, as in the case of the nitrogen, be nearly twice as great as in mere fattening.

Of potash, the Table shows that a given weight of fattening increase retains only about one-eighth as much as it does of phosphoric acid; and the percentage of the whole in the food which is lost to the manure is generally very small. In its case, as in that of the nitrogen and phosphoric acid, the amount retained in mere store increase will be nearly twice as much as in mere fattening increase, but the total quantity retained is still very small. The potash remaining for manure is now valued at 1½*d.* per lb.; instead of 2*d.*, as in 1875, and 2½*d.*, as in 1885.

The last column of Table IX. shows the total manure value of a ton of each of the foods after consumption, reckoning the nitrogen, the phosphoric acid, and the potash at the prices above named, which are those at which they can, at the present time, be purchased in artificial manures. It may be added that the reductions in the prices of ammonia, phosphoric acid, and potash, now adopted, bring all the estimates of total or original manure value almost exactly one-third lower than those given

in 1885. Thus the total manure value of a ton of linseed cake consumed, which in 1885 was reckoned at 3*l.* 18*s.* 6*d.*, is now taken at 2*l.* 11*s.* 11*d.*; that of a ton of maize is reduced from 1*l.* 5*s.* 1*d.* to 16*s.* 7*d.*; and that of other foods in the same proportion.

Unexhausted Manure-value of Cattle Foods.

So much for the method, and the results, of the estimation of the *total* or *original manure value* of the different foods, deducting merely the nitrogen, the phosphoric acid, and the potash, estimated to be retained by the animal consuming them, and reckoning the remainder at the prices at which they can be purchased in artificial manures. We have now to attempt the still more complicated and difficult task of endeavouring to estimate the *unexhausted manure value* of the different foods, or what may be called their *compensation value*, after they have been used for a series of years by the outgoing tenant, and he has realised a certain portion of the manure value in his increased crops.

As already said, we have in the case of a number of the foods endeavoured to estimate the probable amounts of increase that the tenant would obtain in his barley and wheat crops, supposing that the food were used at the rate of one ton per acre in eight years, or one ton over 8 acres each year; and then, after making allowance for loss, we have estimated the value of the unexhausted residue at a declining rate from the last to the eighth year back. These results gave a basis for consideration, and, having studied them, and settled what seemed to be a suitable allowance, we have fixed upon a scale of reduction, starting from the *total or original manure-value*, as estimated in Table IX.

The rule so determined upon is, to deduct one-half of the original manure value of the food used the last year, and one-third of the remainder each year, to the eighth, in the case of all the more concentrated foods, and the roots, in fact of all the foods in the list excepting the hays and the straws; and for these, which contain larger amounts of indigestible matter, and the constituents of which will be more slowly available to crops, two-thirds of the original manure value is deducted for the last year, and only one-fifth from year to year to the eighth year.

The results of the estimates of *compensation value* so made are given in Table X. (p. 33). The first column shows the *total* or *original manure-value* of each food. The second column shows the allowance for the last year, and the succeeding seven

TABLE X.—*Plan and Results of Estimations of the Compensation Value of Unexhausted Manure, starting from the Original Manure Value, that is the Value, deducting the constituents of increase in Fattening Live-Weight only.*

Foods	Original manure value, deducting increase in live-weight only	Compensation value of unexhausted manure							
		Last year	Second year	Third year	Fourth year	Fifth year	Sixth year	Seventh year	Eighth year	Total
DEDUCT ¼ OF ORIGINAL MANURE VALUE THE LAST YEAR, AND ¼ FROM YEAR TO YEAR										
One Ton	£ s. d.	£ s. d.	£ s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	£ s. d.
1. Linseed	1 19 2	0 19 7	0 13 1	8 9	5 10	3 11	2 7	1 9	1 2	2 16 8
2. Linseed cake	2 11 11	1 6 0	0 17 4	11 7	7 9	5 2	3 5	2 3	1 6	3 15 0
3. Decorticated cotton cake	3 14 9	1 17 4	1 4 11	16 7	11 1	7 5	4 11	3 3	2 2	5 7 8
4. Palm-nut cake	1 6 4	0 13 2	0 8 9	5 10	3 11	2 7	1 9	1 2	0 9	1 17 11
5. Undecorticated cotton cake	2 5 3	1 2 7	0 15 1	10 1	6 9	4 6	3 0	2 0	1 4	3 5 4
6. Cocoa-nut cake	1 19 10	0 19 11	0 13 3	8 10	5 11	3 11	2 7	1 9	1 2	2 17 3
7. Rape cake	2 16 5	1 8 3	0 18 10	12 7	8 5	5 7	3 9	2 6	1 8	4 1 7
8. Peas	1 16 5	0 18 3	0 12 2	8 1	5 5	3 7	2 5	1 7	1 1	2 12 7
9. Beans	2 1 11	1 0 11	0 13 11	9 3	6 2	4 1	2 9	1 10	1 3	3 0 2
0. Lentils	2 0 8	1 0 4	0 13 7	9 1	6 1	4 1	2 9	1 10	1 3	2 19 0
1. Tares (seed)	2 1 1	1 0 7	0 13 9	9 2	6 1	4 1	2 9	1 10	1 3	2 19 6
2. Indian corn	0 16 7	0 8 4	0 5 7	3 9	2 6	1 8	1 1	0 9	0 6	1 4 2
3. Wheat	0 18 11	0 9 6	0 6 4	4 3	2 10	1 11	1 3	0 10	0 7	1 7 6
4. Malt	0 17 7	0 8 10	0 5 11	3 11	2 7	1 9	1 2	0 9	0 6	1 5 5
5. Barley	0 17 2	0 8 7	0 5 9	3 10	2 7	1 9	1 2	0 9	0 6	1 4 11
6. Oats	0 19 9	0 9 11	0 6 7	4 5	2 11	1 11	1 3	0 10	0 7	1 8 5
7. Rice meal	(0 18 6)	(0 9 3)	(0 6 2)	(4 1)	(2 9)	(1 10)	(1 3)	(0 10)	(0 7)	(1 6 9)
8. Locust beans	—	—	—	—	—	—	—	—	—	—
9. Malt coombs	2 6 7	1 3 3	0 15 6	10 4	6 11	4 7	3 1	2 1	1 5	3 7 2
0. Fine pollard	1 15 2	0 17 7	0 11 9	7 10	5 3	3 6	2 4	1 7	1 1	2 10 11
1. Coarse pollard	1 18 1	0 19 1	0 12 9	8 6	5 8	3 9	2 6	1 8	1 1	2 15 0
2. Bran	1 18 6	0 19 3	0 12 10	8 7	5 9	3 10	2 7	1 9	1 2	2 15 9
DEDUCT ½ OF ORIGINAL MANURE VALUE THE LAST YEAR, AND ½ FROM YEAR TO YEAR										
One Ton										
3. Clover hay	1 7 0	0 9 0	0 7 2	5 9	4 7	3 8	2 11	2 4	1 10	1 17 3
4. Meadow hay	0 18 7	0 6 2	0 4 11	3 11	3 2	2 6	2 0	1 7	1 3	1 5 6
5. Pea straw	0 12 2	0 4 1	0 3 3	2 7	2 1	1 8	1 4	1 1	0 10	0 16 11
6. Oat straw	0 7 5	0 2 6	0 2 0	1 7	1 3	1 0	0 10	0 8	0 6	0 10 4
7. Wheat straw	0 6 6	0 2 2	0 1 9	1 5	1 2	0 11	0 9	0 7	0 6	0 9 3
8. Barley straw	0 6 5	0 2 2	0 1 9	1 5	1 2	0 11	0 9	0 7	0 6	0 9 3
9. Bean straw	0 11 5	0 3 10	0 3 1	2 6	2 0	1 7	1 3	1 0	0 10	0 16 1
DEDUCT ¼ OF ORIGINAL MANURE VALUE THE LAST YEAR, AND ½ FROM YEAR TO YEAR										
Ten Tons										
0. Potatoes	2 0 10	1 0 5	0 13 7	9 1	6 1	4 1	2 9	1 10	1 3	2 19 1
1. Carrots	1 7 6	0 13 9	0 9 2	6 1	4 1	2 9	1 10	1 3	0 10	1 19 9
2. Parsnips	1 15 0	0 17 6	0 11 8	7 9	5 2	3 5	2 3	1 6	1 0	2 10 3
3. Mangel wurzels	1 11 8	0 15 10	0 10 7	7 1	4 9	3 2	2 1	1 5	0 11	2 5 10
4. Swedish turnips	1 9 2	0 14 7	0 9 9	6 6	4 4	2 11	1 11	1 3	0 10	2 2 1
5. Yellow turnips	(1 5 0)	(0 12 6)	(0 8 4)	(5 7)	(3 9)	(2 6)	(1 8)	(1 1)	(0 9)	(1 16 2)
6. White turnips	1 5 10	0 12 11	0 8 7	5 9	3 10	2 7	1 9	1 2	0 9	1 17 4

columns that for each succeeding year to the eighth. The last column gives the *total compensation value* for the eight years' consumption.

It may seem at first sight that a deduction of 50 per cent. from the original manure value of the food used in the last year is large; but we have not only to make allowance for all losses to which the manure may be subject, which may be considerable, especially if much of the food is consumed in the yards; but it is also to be borne in mind that the money paid for compensation will not yield its full return for a long time. Only half the original manure value would, therefore, be allowed if the food were only used one year; and all scales of allowance arranged by Farmers' Clubs assume the consumption for more than one year. If, however, the food is used for eight years, or more, it will be seen that the total allowance considerably exceeds the original manure value of one year's consumption; the allowance made for the accumulation bringing it up to from one and a third to one and a half as much as the original manure value.

In order to test the applicability of the scale of compensation proposed, let us take a very simple and ordinary case, and see what would be the allowance allotted to the outgoing tenant according to the estimate given in the Table. Let us suppose the case of a Norfolk or Lincolnshire farm under the ordinary four-course rotation, with meat and grain only sold, the roots fed partly on the land and partly in the yards. Assume, further, that the land is thoroughly clean, and that the farm is in every respect in good order when given up. It is pretty certain, indeed, that every claim for compensation will have to be settled on its own merits; that the character of the soil, the cropping, the state of the land as to cleanliness, and many other points will be taken into consideration, both for and against any claim.

As already intimated, the essential basis of the system of estimate and valuation of the unexhausted residue adopted is the assumption of gradual accumulation within the soil, and of slow recovery from it. Suppose then that linseed cake had been used annually for eight years, at the average rate of one ton over eight acres each year, or of one ton per acre in eight years. Each acre would thus on the average receive, either in farmyard manure or directly by the feeding with roots or clover on the land, the manure from the consumption of one ton of linseed cake in eight years, or at the average rate of one-eighth of a ton, or 2½ cwt., per acre, per annum.

The first column of Table X. (p. 33) shows that the *total or*

original manure value of one ton of linseed cake consumed—that is, the value deducting only the constituents stored up in the animal—is estimated to be 2*l.* 11*s.* 11*d.* The subsequent columns of the same Table show the estimated *compensation value* of the *unexhausted residue* from one ton consumed (that is, after the tenant has realised the benefit of the increase of his crops) to be, if used each year for eight years, as given in the first column of the following Table, the second column showing the amount per acre per annum :—

	Compensation allowances for one ton of linseed cake consumed	
	Per annum, eight years	Per acre, in eight years
	£ s. d.	£ s. d.
Last year	1 6 0	0 3 3
2nd „	0 17 4	0 2 2
3rd „	0 11 7	0 1 5
4th „	0 7 9	0 1 0
5th „	0 5 2	0 0 8
6th „	0 3 5	0 0 5
7th „	0 2 3	0 0 3
8th „	0 1 6	0 0 2
Total	3 15 0	0 9 4

Thus, according to the first column of the Table, the value of the unexhausted manure residue from the consumption of one ton of linseed cake annually for eight years would be 3*l.* 15*s.* 0*d.*, or nearly 45 per cent. more than the original manure value of one year's consumption. Or, as the second column shows, the allowance would be at the rate of 9*s.* 4*d.* per acre over the whole farm.

Whether such an allowance would be too much or too little under the circumstances supposed is a question for consideration. The conditions supposed are: a light-land farm, upon which the manure from purchased food is an essential element of profitable cultivation; that meat and grain alone are sold; and that the farm is given up in a satisfactory state in every respect. Also that, on the average, each acre received during the last eight years, the manure derived from the consumption of one ton of linseed cake. The question between the two parties concerned is, whether the outgoing tenant would receive sufficient remuneration for his unexhausted manure; and, on the other hand, whether the landowner, or the incoming tenant, would pay more than will be recovered in increase of crops? An allowance of 9*s.* 4*d.* per acre on a farm of 400 acres would

amount to 186*l.* 13*s.* 4*d.*, which is a large sum to pay; and it is certain that the recovery of the amount will only be gradual. It is well known that both time and money are required to get land into condition, and here is land already in condition.

Let us consider the effect of such a valuation of unexhausted manure from two opposite points of view. The outgoing tenant may consider that he is entitled to a larger sum, and he prefers to claim compensation under the Act. The outgoing tenant of the future will, however, have another alternative. He can reduce the stock of fertility by the consumption of foods which have high feeding, but low manure, value, and which are lower in price than the foods which possess both high feeding, and high manure, value. The incoming tenant knows what he has to pay for, and has only himself to blame if he pays too much. But behind the incoming tenant is the landowner, who must himself pay the claim of the outgoing tenant if he can find no one else to do so. It is, therefore, a matter of importance to the landlord that the compensation should be fixed on a basis sufficiently reasonable to render it not worth his while to carry the case to arbitration, or into a court of law.

As before referred to, we have, in the construction of the Table (X., p. 33), in all cases adopted one uniform rate of deduction from year to year, excepting in those of the hays and the straws, as already explained, and as shown in the Table. We do not, however, at all assume that there is no difference in the activity of the manure from the different foods thus classed together, or that their unexhausted residue will be available at exactly the same rate. Then, again, it is obvious that to assume the consumption, and the manure value, to be the same on each acre, and in each year, is not strictly in accordance with the facts. But to have attempted to fix a different scale for each food, and for each year, according to the varying circumstances, would have been to assume a knowledge which we do not possess; and we submit the Table for the consideration of those interested, as the best approximation to the truth that we are at present able to provide.

Although it is to be borne in mind that the whole of the estimates are founded on the assumption that fattening increase only is produced, yet we have indicated the direction, and indeed to a considerable extent the degree, in which the figures should be modified when store animals are reared or fed. It should be added that, in the case of the foods being used for the production of milk, an entirely different scale of original and unexhausted manure value would have to be arranged, as milk

removes so very much more of the manure constituents of the food than increase in live-weight of any kind.

Further, it will be understood that our tables do not claim to be applicable to cases of the liberal use of town manures, perhaps for the growth of potatoes or other market garden crops for sale. Such cases require special consideration, and come under the description of garden rather than of farm cultivation.

In conclusion, although we have revised the estimates of the manure values of food stuffs, in accordance with the prices of ammonia, phosphoric acid, and potash, at the present time, the results will doubtless require further revision from time to time, as the value of manure constituents in the market changes, and perhaps also in other ways, as knowledge advances and experience is gained. But, in view of the problems and the discussions to which the issue of the Final Report of the Royal Commission on Agricultural Depression must necessarily give rise, it seemed opportune to bring the subject up to date on the present occasion. It is to be understood, however, that in the use of the Tables, the special circumstances of each case must be taken into account, and the actual figures adopted, or modification made, accordingly. At any rate, as we have given the data on which our estimates are founded, and explained the method by which they have been obtained, those interested in this most difficult subject have the means of forming their own conclusions on the results arrived at.

General Observations and Conclusions.

It is now proposed that compensation should be given, when produce grown on the farm, which at present the tenant is expected to sell, is consumed at home, by cattle, sheep, or pigs, or by horses other than those used on the farm. The justice of the proposal is based on the fact that the tenant could claim compensation if he used purchased food instead, and that it seems unreasonable that he should be obliged to send his home-grown produce to market and bring back imported cattle food, to establish his claim for compensation, when it would be more profitable to him, and the land might be equally benefited, if he consumed his own produce. There may, however, be considerable difficulty in carrying out such an arrangement. For example, under existing conditions farmers do consume more or less of their home-grown produce. The offal wheat and barley are at any rate so used. Then, if the barley is injured by the weather, and rendered unfit for malting, as was the case to so great an extent in some counties in 1896, a considerable quantity may be more profitably consumed than sold; and the

question arises whether the tenant should be compensated for consuming his home-grown produce under such circumstances?

In the case of those light soils for which imported fertility is an essential of their profitable cultivation, the consumption of home-grown produce may sometimes be advantageous, and it would certainly help to keep down the bill for cake and other imported foods. But there is a large area of soils in the country which themselves contain vast stores of inherent fertility, for the utilisation of which, however, tillage operations are of as much importance as manures; and the question arises whether in the case of such soils, farmed under the ordinary rotation and covenants of the district, they are not of themselves competent to yield good crops without detriment to the permanent fertility of the land. It has been shown that in the case of the land in our own district, the removal of a certain portion of the soil constituents has been carried on over a long period of time without such injury; and it is a question whether, if a moderate proportion of the produce now sold were consumed on the farm, the land would be materially benefited; though, if the claim proposed were made legal, the owner or the incoming tenant might be subject to payment for compensation. At any rate it is certain that there would be difficulty in carrying out such an arrangement, and that much discrimination will be required on the part of the valuer.

It is true that the heavier soils yield much larger crops than they otherwise would, when aided by imported fertility, derived from the use of purchased cattle foods or direct manures; but the illustrations which have been given show that such soils retain the unexhausted residue of manure very tenaciously; and they do so much more than lighter soils, and so yield up the constituents to future crops much more slowly. Claims for compensation for unexhausted manures would, therefore, be more difficult to establish in the case of the heavier than of the lighter soils.

It may here be observed that we have made some attempts to calculate to what extent the crops of the country at large are increased by imported fertility in the form of cattle foods and manures. But so much of some of the larger articles of consumption, such as Indian corn, peas, beans, &c., are used in towns, that it was found impossible to determine how much of the quantities of them imported were probably consumed in agriculture. With regard to cakes, it may be said that if the whole of the imports were considered to be employed evenly over the arable and grass land of Great Britain, the consumption per acre would be very small indeed.

From the illustrations given, and discussions upon them, it will be seen that in the application of our tables of compensation value we consider that the distinction between light and heavy soils must be clearly borne in mind, the claim being much the greater, and much the more easily estimated, in the case of the lighter than of the heavier soils. In the one case imported fertility is essential to profitable cultivation, and the unexhausted manures are more rapidly available; whereas in the other, tillage operations are of the greater importance, and imported fertility of much less, whilst the unexhausted residue of such fertility is much more slowly available. An illustration of this was afforded in the case of the experiments at Rothamsted on the growth of barley by means of rape cake for forty years in succession (see pp. 11–13).

In conclusion, it is obvious that if the occupier is to be compensated for the consumption on the holding of home-grown produce, which he is now permitted to sell, and if he is also to be free to grow and sell what he pleases, and yet must maintain the fertility of the soil, the difficulties of the valuer will be very greatly increased; and the referee who is to decide upon conflicting claims must be a man of extraordinary sagacity if he can settle the disputes that will arise to the satisfaction of both parties. It is to be hoped, however, that under the provisions of any future *Agricultural Holdings Act* the settlement of disputes will be speedy, cheap, and effectual, and that the successful party will not find himself a loser in the transaction.

The more directly practical conclusions may be briefly summarised as follows:—

1. When manures containing organic matter, such as those produced by the consumption of hay, straw, cakes, corn, &c., have been applied to the soil and grown a crop, the unexhausted residue of their fertilising constituents is yielded up to future crops only gradually, but much more rapidly on light than on heavy soils. Much the same may be said when organic matters, such as rape cake, are directly used as manures.

2. The value of the manure produced by the consumption of different cattle foods varies very greatly, and depends upon their composition. This is fully illustrated in the foregoing pages, and especially in Tables IX. and X. (pp. 28–29, and 33).

3. When nitrate of soda is used as manure, its nitrogen does not enter into fixed combinations within the soil, but nitrate is dissolved in the soil-water, and unless taken up by vegetation,

much passes into the drains, or into the subsoil beyond the reach of the roots of the crops. When salts of ammonia are used, part of the ammonia is temporarily taken up by the soil, but it is, more or less rapidly (according to the character of the soil and of the season), converted into nitrate, and is then subject to loss by drainage as when nitrate of soda is used. The loss by drainage will, as a rule, be the most when these manures are applied to grain crops, but materially less when applied to root-crops or to permanent grass, as these crops have a more extended period of growth, tending to keep the soil-water nearer the surface, and to greater utilisation of the nitrogen.

4. When these artificial nitrogenous manures are used for grain crops, they leave some nitrogenous crop-residue (stubble and roots); the more the greater the amount of increased produce due to the manure. When used for root-crops, there will, as a rule, be much more of the supplied nitrogen recovered in the crop than in the total produce (grain and straw) of a grain crop. When applied to permanent grass, there will also be much more of the supplied nitrogen recovered in the increase of crop than when applied to a grain crop; and there will at the same time be more crop-residue in the case of permanent grass than in that of a grain crop.

5. When superphosphate, basic slag, kainit, or salts of potash, are applied as manure, a portion of the phosphoric acid and potash is readily taken up by vegetation; but a large quantity soon enters into fixed combinations within the soil, especially in the case of the heavier soils, and this is very slowly available to future crops. Hence the compensation value of the unexhausted residue of these manures is very small.

6. To draw a distinction between the landowner's and the tenant's fertility, and to assign a commercial value to the latter, must always be a difficult matter; and especially must it be so, as some soils contain vast stores of natural fertility, and others very little. It is to be hoped that the evidence which has been brought forward, and the comments upon it, may be of some service to those who are called upon to act as valuers in cases where questions of compensation for unexhausted manures become subjects of dispute.

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Rothamsted.

THE

VALUATION OF THE MANURES

OBTAINED BY THE

CONSUMPTION OF FOODS

FOR THE

PRODUCTION OF MILK.

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1898.

THE VALUATION OF THE MANURES OBTAINED BY THE CONSUMPTION OF FOODS FOR THE PRODUCTION OF MILK.

AFTER the publication in 1885 of our paper in this Journal on "*The Valuation of Unexhausted Manures*," in which we limited our illustrations to cases of the manures obtained by the consumption of foods for the production of fattening increase, we were asked if we could not supply a scale applicable to the consumption of foods for the production of milk. Again, since the publication of our revised valuations in the last issue of the Journal,[1] we have been asked the same question. In answer, we in each case pointed out how such an estimate could approximately be arrived at. There are, however, considerable difficulties in extending the valuations to meet the requirement in the case of milk-production, as will be fully appreciated as we proceed. After careful consideration of the subject we have, however, arranged tables of valuation of the manure obtained when food is consumed for the production of milk, substantially on the plan of those previously given in the case of the production of fattening increase.

In illustration of the complexity and difficulty of the subject, it will be of interest to recall attention here to illustrations we have previously given, of the great difference in the demands made upon the food, on the one hand for the production of animal increase, and on the other for the production of milk. As is well known, not only do cows of different breeds yield widely different quantities of milk, and in some cases milk of characteristically different composition, but individual animals of the same breed have very different milk-yielding capacity; and whatever the average capacity of a cow may be, she has a maximum yield at one period of her lactation, which is followed by a gradual decline. Hence, in comparing the amounts of constituents stored up in the fattening increase of an ox with the amounts of the same constituents removed in the milk of a cow, we must assume a wide range of difference in the yield of milk.

[1] Journal R.A.S.E., 3rd series, vol. viii. 1897, part iv. p. 674.

Table I. shows the amounts—of nitrogenous substance, of fat, of non-nitrogenous substance not fat, of total mineral matter, of phosphoric acid, of potash, and of total solid matter, carried off in the weekly yield of milk of a cow, on the alternative assumptions of a produce of 4, 6, 8, 10, 12, 14, 16, 18, or 20 quarts, per head per day; and, for comparison, there are given at the bottom of the Table the amounts—of nitrogenous substance, of fat, of total mineral matter, of phosphoric acid, of potash, and of total solid matter, in the weekly increase in live-weight of a fattening ox, of an average weight

TABLE I.—*Comparison of the Constituents of Food carried off in Milk, and in the Fattening Increase of Oxen.*

[1 Gallon = 10·33 lb.]	Nitrogenous substance	Fat	Non-nitrogenous substance not fat (sugar)	Total mineral matter (ash)	Phosphoric acid	Potash	Total solid matter
IN MILK PER WEEK.							
If:—	lb.	lb.	lb.	lb.	lb.	lb.	lb.
4 quarts per head per day	2·64	2·53	3·33	0·54	0·1566	0·1350	9·04
6 " "	3·96	3·80	4 99	0·81	0·2349	0·2025	13·56
8 " "	5·28	5·06	6·66	1·08	0·3132	0·2700	18·08
10 " "	6·60	6·33	8·32	1·35	0·3915	0·3375	22·60
12 " "	7·92	7·59	9·99	1·62	0·4698	0·4050	27·12
14 " "	9·24	8·86	11·65	1·89	0·5481	0·4725	31·64
16 " "	10·56	10·12	13·32	2·16	0·6264	0·5400	36·16
18 " "	11·88	11·39	14·98	2·43	0·7047	0·6075	40·68
20 " "	13·20	12·65	16·65	2·70	0·7830	0·6750	45·20
IN INCREASE IN LIVE-WEIGHT PER WEEK (OXEN).							
If 10 lb. increase .	0·80	6·35	—	0·20	0·086	0·011	7·35
If 15 lb. increase .	1·20	9·53	—	0·30	0·129	0 0165	11·03

of 1,000 lb.—first on the assumption of a weekly increase of 10 lb., and secondly of 15 lb.

The estimates of the amounts of constituents in the milk are based on the assumption that it will contain 12·5 per cent. of total solids, consisting of 3·65 albuminoids, 3·50 butter-fat, 4·60 sugar, and 0·75 total mineral matter; the last containing 0·22 (0·2175) phosphoric acid, and 0·19 (0·1875) potash. The estimates of the constituents in the fattening increase of oxen are founded on determinations made at Rothamsted. On this point it may be added, that the amounts of nitrogenous substance in the animal increase are slightly raised from the original estimate, first published in 1885, and they now accord with that

adopted in our valuation tables published in 1885, and again in 1897. The amount of total mineral matter in the increase is also somewhat raised from the original estimate; partly from the consideration that, with earlier maturity, the so-called fattening increase will contain more of growth, and hence somewhat more of both nitrogen and mineral matter, than was assumed in our earlier adopted average estimates.

Referring to the very wide range of yield of milk per head per day which the figures in the Table assume, it may be remarked that it is by no means impossible that the same animal might yield the largest amount—namely, 20 quarts, or 5 gallons, per day, near the beginning, and only 4 quarts, or 1 gallon, or even less, towards the end of her period of lactation. At the same time, a moderately large herd of, say Shorthorns or Ayrshires, of fairly average quality, well fed, and including animals of various periods of lactation, should not yield an average of less than 8 quarts, or 2 gallons, and would seldom exceed 10 quarts, or 2½ gallons, per head per day, the year round.

For the purposes of illustration, we will assume an average yield of milk of 10 quarts, equal 2½ gallons, or between 25 and 26 lb. per head per day; and compare the amount of constituents in the weekly yield at this rate, with that in the weekly increase of the fattening ox at the higher rate assumed in the Table—namely, 15 lb. per 1,000 lb. live-weight, or 1·5 per cent., per week.

Thus, of the nitrogenous substance of the food, the amount stored up in the fattening increase of the ox will be only 1·2 lb., but the amount carried off as such in the milk would be 6·6 lb., or 5½ times as much as in the increase. Of mineral matter, again, the fattening increase would not contain more than 0·3 lb.; whilst the milk would carry off 1·35 lb. or 4½ times as much; of phosphoric acid, the increase would contain 0·129 lb. and the milk 0·3915 lb. or more than 3 times as much; and of potash, the fattening increase would contain 0·0165 lb., but the milk 0·3375 lb., or more than 20 times as much.

Although the fact has no bearing on our present estimates, it is of interest to observe that, whilst the fattening increase would contain 9·53 lb. of fat, the milk would contain only 6·33 lb., or only about two-thirds as much. On the other hand, whilst the fattening increase contains practically no other non-nitrogenous substance besides fat, the milk would carry off 8·32 lb. in the form of milk-sugar. It may be added, that this amount of milk-sugar reckoned as fat would correspond approximately to the difference between the fat in the milk and that in the fattening increase.

From the foregoing comparisons, it is evident that the drain upon the food is very much greater for the production of milk than for that of meat; leaving, therefore, correspondingly smaller amounts of the constituents consumed remaining for manure. This is especially the case in the important item of nitrogenous substance; and if, as is frequently assumed, the butter-fat of the milk is, at any rate to a great extent, primarily derived from the nitrogenous substance of the food, so far as it is so, about two parts of such substance would be required to produce one of fat. On such an assumption, therefore, the requirement for nitrogenous substance of food would be much greater than that indicated in the Table (I.) as existing as nitrogenous substance in the milk. But the nitrogen of any amount of nitrogenous substance so utilised for the production of fat would nevertheless be recovered in the manure.

Independently, however, of the difficulty of estimating the average value of the manure derived from the consumption of food for the production of milk, arising from the very wide difference in the amount of milk yielded by different cows, or by the same cow at different periods of her lactation, our knowledge as to the difference in the amount of the food actually consumed by the animal coincidently with the production of such different amounts of milk, is far from definite and trustworthy. The difference in the amounts of consumption in relation to production will, however, be much less, and will less materially vitiate estimates of manure-value in the case of herds; especially if the individuals are selected with ordinary judgment as to milk-yielding capacity, and period of lactation, and if the feeding is also managed with judgment, under the guidance of experience.

Although information is wanting to enable us to connect, with numerical accuracy, the great differences in milk-yield of individual cows with the coincident differences in consumption to produce it, it may be considered as satisfactorily established, by the results of ourselves and others in this country, that more food is consumed by a herd of cows to produce a fair yield of milk, of say 8 or 10 quarts per head per day, than by an equal live-weight of oxen fed to produce fattening increase.[1] In the cases supposed, it may, for practical purposes, be assumed that

[1] In making the above statement, we are fully aware that in Wolff's *Tables of Standard Rations*, he assumes that milch cows will consume less total dry matter of food, and also less of digestible nitrogenous substance, non-nitrogenous substance, and total organic substance, for a given live-weight per day than fattening oxen. This is, however, certainly not the case with fairly well-bred and liberally fed cows in this country, giving good yields of milk.

the cows would consume about one-fourth more food than the oxen. Accordingly, in our estimates of the value of the manure obtained on the consumption of food for the production of milk, we have assumed that one-fourth more will be consumed by 1,000 lb. live-weight of cows than by the same weight of oxen; but the estimates of the amounts of the constituents of the food removed in the milk, or remaining for manure, are nevertheless reckoned per ton of each food consumed, as in the case of those relating to feeding for the production of fattening increase. It may be added, that the calculations of the amounts of the constituents in the milk are based on the same average composition of milk as is adopted in the construction of Table I. (p. 4), and described in detail in the letterpress at pp. 4–5. Thus, the nitrogen is taken at 0·579 (=3·65 nitrogenous substance) per cent., the phosphoric acid at 0·2175 per cent., and the potash at 0·1875 per cent., in the milk.

Table II. (pp. 8–9) shows in detail the estimate of the amount of nitrogen in one ton of each food, and in the milk produced from its consumption, on the assumption of an average yield of 10 quarts per head per day; also the amount remaining for manure the amount of ammonia corresponding to the nitrogen, and the value of the ammonia at 4*d.* per lb. Similar particulars are also given in relation to the phosphoric acid and the potash, consumed in the food, removed in the milk, and remaining for manure, &c. This table will serve as a sufficient illustration of the mode of estimating the *total or original* value of the manure, derived from the consumption of the different foods for the production of milk in the case supposed; that is assuming an average yield of a herd of 10 quarts per head per day.

We have, however, made similar detailed calculations of the *total or original* manure-value (as in Table II. for 10 quarts), on the alternative assumptions of a yield of 6, 8, 12, and 14 quarts, per head per day; and, so far as the estimates of the *total or original manure-value* are concerned, the results for the various amounts of milk-yield are given in Table III. (p. 10). For comparison there is also given, in the first column, the estimate of the *total or original* manure-value when the foods are consumed for the production of fattening increase.

So much for the plan and results of the estimations of the *total or original* manure-value of the different foods, that is deducting only the constituents removed in the milk, and reckoning the remainder at the prices at which they can be purchased in artificial manures. With a view to direct application to practice, however, we have now to endeavour to estimate the

[*continued on p.* 11

TABLE II.—*Estimates of the Total or Original Manure-value of Milk. Valuations on the assumption of an average pro-*

Nos.	Description of food	Nitrogen				
		In 1 ton of food	In milk from 1 ton of food	In manure		
				Total remaining for manure	Nitrogen equal ammonia	Value of ammonia at 4*d.* per lb.
		lb.	lb.	lb.	lb.	£ s. d.
1	Linseed	80·64	25·04	55·60	67·52	1 2 6
2	Linseed cake	106·40	20·86	85·54	103·87	1 14 7
3	Decorticated cotton cake	147·84	19·27	128·57	156·13	2 12 1
4	Palm-nut cake	56·00	17·86	38·14	46·31	0 15 5
5	Undecorticated cotton cake	84·00	15·66	68·34	82·99	1 7 8
6	Cocoa-nut cake	76·16	15·66	60·50	73·47	1 4 6
7	Rape cake	109·76	12·50	97·26	118·11	1 19 4
8	Peas	80·64	17·86	62·78	76·24	1 5 5
9	Beans	89·60	17·86	71·74	87·12	1 9 0
10	Lentils	94·08	17·86	76·22	92·56	1 10 10
11	Tares (seed)	94·08	17·86	76·22	92·56	1 10 10
12	Indian corn	38·08	17·38	20·70	25·14	0 8 5
13	Wheat	40·32	17·38	22·94	27·86	0 9 3
14	Malt	38·08	17·86	20·22	24·55	0 8 2
15	Barley	36·96	17·38	19·58	23·78	0 7 11
16	Oats	44·80	16·68	28·12	34·15	0 11 5
17	Rice meal	42·56	16·68	25·88	31·43	0 10 6
18	Locust beans	26·88	13·90	12·98	15·76	0 5 3
19	Malt coombs	87·36	15·66	71·70	87·07	1 9 0
20	Fine pollard	54·88	16·68	38·20	46·39	0 15 6
21	Coarse pollard	56·00	15·66	40·34	48·99	0 16 4
22	Bran	56·00	13·90	42·10	51·12	0 17 0
23	Clover hay	53·76	8·94	44 82	54·43	0 18 2
24	Meadow hay	33·60	8·36	25·24	30·65	0 10 3
25	Pea straw	22·40	7·83	14·57	17·69	0 5 11
26	Oat straw	11·20	6·95	4·25	5·16	0 1 9
27	Wheat straw	10·08	5·98	4·10	4·98	0 1 8
28	Barley straw	8·96	5·46	3·50	4·25	0 1 5
29	Bean straw	20·16	5·68	14·48	17·58	0 5 10
30	Potatoes	5·60	2·07	3·53	4·29	0 1 5
31	Carrots	4·48	1·46	3·02	3·67	0 1 3
32	Parsnips	4·93	1·67	3·26	3·96	0 1 4
33	Mangel wurzels	4·93	1·32	3·61	4·38	0 1 6
34	Swedish turnips	5·60	1·14	4·46	5·42	0 1 10
35	Yellow turnips	4·48	0·93	3·55	4·31	0 1 5
36	White turnips	4·03	0·84	3·19	3·87	0 1 3

Cattle Foods after Consumption by Cows for the Production of duction by a herd, of 10 *quarts of milk per head per day.*

Phosphoric Acid				Potash				Total or original manure-value per ton of food consumed
In 1 ton of food	In milk from 1 ton of food	In manure		In 1 ton of food	In milk from 1 ton of food	In manure		
		Total remaining for manure	Value at 2d. per lb.			Total remaining for manure	Value at 1½d. per lb.	
lb.	lb.	lb.	s. d.	lb.	lb.	lb.	s. d.	£ s. d.
34·50	9·34	25·16	4 2	30·69	8·02	22·67	2 10	1 9 6
44·80	7·79	37·01	6 2	31·36	6·71	24·65	3 1	2 3 10
69·44	7·18	62·26	10 5	44·80	6·22	38·58	4 10	3 7 4
26·88	6·68	20·20	3 4	11·20	5·73	5·47	0 8	0 19 5
44·80	5·85	38·95	6 6	44·80	5·07	39·73	5 0	1 19 2
31·36	5·85	25·51	4 3	44·80	5·07	39·73	5 0	1 13 9
56·00	4·69	51·31	8 7	33·60	4·09	29·51	3 8	2 11 7
19·04	6·68	12·36	2 1	21·50	5·73	15·77	2 0	1 9 6
24·64	6·68	17·96	3 0	29·12	5·73	23·39	2 11	1 14 11
16·80	6 68	10·12	1 8	15·68	5·73	9·95	1 3	1 13 9
17·92	6·68	11·24	1 10	17·92	5·73	12·19	1 6	1 14 2
13·44	6·50	6·94	1 2	8·29	5·56	2·73	0 4	0 9 11
19·04	6·50	12·54	2 1	11·87	5·56	6·31	0 9	0 12 1
17·92	6·68	11·24	1 10	11·20	5·73	5·47	0 8	0 10 8
16·80	6·50	10·30	1 9	12·32	5·56	6·76	0 10	0 10 6
13·44	6 24	7·20	1 2	11·20	5·40	5·80	0 9	0 13 4
(13·44)	6·24	7·20	1 2	(8·29)	5·40	2 89	0 4	0 12 0
—	5·19	—	—	—	4·42	—	—	—
44·80	5·85	38·95	6 6	44·80	5·07	39·73	5 0	2 0 6
64·96	6·24	58·72	9 9	32·70	5·40	27·30	3 5	1 8 8
78·40	5·85	72·55	12 1	33·60	5·07	28·53	3 7	1 12 0
80·64	5·19	75·45	12 7	32·48	4·42	28·06	3 6	1 13 1
12·77	3·35	9·42	1 7	33·60	2·94	30·66	3 10	1 3 7
8·96	3·10	5·86	1 0	35·84	2·62	33·22	4 2	0 15 5
7·84	2·91	4·93	0 10	22·40	2·46	19·94	2 6	0 9 3
5 38	2·60	2·78	0 6	22·40	2·29	20·11	2 6	0 4 9
5·38	2·23	3·15	0 6	17·92	1·96	15·96	2 0	0 4 2
4·03	2·04	1·99	0 4	22·40	1·80	20·60	2 7	0 4 4
6·72	2·14	4·58	0 9	22 40	1·80	20·60	2 7	0 9 2
3·36	0·78	2·58	0 5	12·32	0·66	11·66	1 5	0 3 3
2·02	0·54	1·48	0 3	6·27	0·49	5·78	0 9	0 2 3
4·26	0·63	3·63	0 7	8·06	0·49	7 57	0 11	0 2 10
1·57	0·49	1·08	0 2	8·96	0·49	8·47	1 1	0 2 9
1·34	0 44	0·90	0 2	4·93	0·33	4·60	0 7	0 2 7
(1·34)	0·34	1·00	0 2	(4·93)	0·33	(4·60)	0 7	0 2 2
1·12	0·31	0·81	0 2	6·72	0·33	6·39	0 10	0 2 3

TABLE III.—*Comparison of the Estimates of Total or Original Manure-value when Foods are consumed for the Production of Fattening Increase, with those when the Food is consumed by Cows giving different yields of Milk.*

Nos.	Description of food	Total or original manure-value per ton of food consumed—that is, only deducting the constituents in fattening increase or in milk																	
		For the production of fattening increase			For the production of milk, supposing the yield per head per day to be as under—														
					6 quarts			8 quarts			10 quarts			12 quarts			14 quarts		
		£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.
1	Linseed	1	19	2	1	14	7	1	12	0	1	9	6	1	7	1	1	4	5
2	Linseed cake	2	11	11	2	8	1	2	6	0	2	3	10	2	1	9	1	19	8
3	Decorticated cotton cake	3	14	9	3	11	2	3	9	2	3	7	4	3	5	4	3	3	4
4	Palm-nut cake	1	6	4	1	3	2	1	1	4	0	19	5	0	17	9	0	15	11
5	Undecorticated cotton cake	2	5	3	2	2	4	2	0	8	1	19	2	1	17	6	1	15	11
6	Cocoa-nut cake	1	19	10	1	16	11	1	15	3	1	13	9	1	12	3	1	10	6
7	Rape cake	2	16	5	2	14	2	2	12	11	2	11	7	2	10	4	2	9	1
8	Peas	1	16	5	1	13	1	1	11	2	1	9	6	1	7	8	1	5	9
9	Beans	2	1	11	1	18	7	1	16	10	1	14	11	1	13	1	1	11	4
10	Lentils	2	0	8	1	17	5	1	15	7	1	13	9	1	12	2	1	10	1
11	Tares (seed)	2	1	1	1	17	11	1	16	0	1	14	2	1	12	6	1	10	7
12	Indian corn	0	16	7	0	13	4	0	11	7	0	9	11	0	8	1	0	6	5
13	Wheat	0	18	11	0	15	8	0	13	11	0	12	1	0	10	5	0	8	8
14	Malt	0	17	7	0	14	5	0	12	7	0	10	8	0	9	0	0	7	1
15	Barley	0	17	2	0	14	0	0	12	3	0	10	6	0	8	8	0	6	11
16	Oats	0	19	9	0	16	8	0	15	0	0	13	4	0	11	7	0	9	10
17	Rice meal	(0	18	6)	0	15	5	0	13	9	0	12	0	0	10	5	0	8	7
18	Locust beans		—			—			—			—			—			—	
19	Malt coombs	2	6	7	2	3	9	2	2	0	2	0	6	1	18	11	1	17	4
20	Fine pollard	1	15	2	1	12	0	1	10	5	1	8	8	1	6	11	1	5	3
21	Coarse pollard	1	18	1	1	15	2	1	13	6	1	12	0	1	10	5	1	8	9
22	Bran	1	18	6	1	15	11	1	14	6	1	13	1	1	11	8	1	10	3
23	Clover hay	1	7	0	1	5	5	1	4	5	1	3	7	1	2	8	1	1	8
24	Meadow hay	0	18	7	0	17	0	0	16	3	0	15	5	0	14	5	0	13	7
25	Pea straw	0	12	2	0	10	9	0	10	0	0	9	3	0	8	5	0	7	8
26	Oat straw	0	7	5	0	6	2	0	5	5	0	4	9	0	4	0	0	3	3
27	Wheat straw	0	6	6	0	5	5	0	4	10	0	4	2	0	3	6	0	3	0
28	Barley straw	0	6	5	0	5	6	0	4	10	0	4	4	0	3	9	0	3	2
29	Bean straw	0	11	5	0	10	4	0	9	9	0	9	2	0	8	7	0	8	0
30	Potatoes	0	4	1	0	3	9	0	3	6	0	3	3	0	3	1	0	2	11
31	Carrots	0	2	9	0	2	6	0	2	4	0	2	3	0	2	1	0	1	11
32	Parsnips	0	3	6	0	3	3	0	3	1	0	2	10	0	2	8	0	2	7
33	Mangel wurzels	0	3	2	0	3	0	0	2	10	0	2	9	0	2	7	0	2	5
34	Swedish turnips	0	2	11	0	2	9	0	2	8	0	2	7	0	2	5	0	2	3
35	Yellow turnips	(0	2	6)	0	2	4	0	2	3	0	2	2	0	2	1	0	2	0
36	White turnips	0	2	7	0	2	5	0	2	4	0	2	3	0	2	2	0	2	0

unexhausted manure-value of the different foods, or what may be called their *compensation-value*, after they have been used for a series of years by the outgoing tenant, and he has realised a certain portion of the manure-value in his increased crops. In the calculations we have adopted the same scale of reduction of the manure-value from year to year as in the case of the manure derived from the consumption of the foods for the production of fattening increase; and we must refer to the Section—"*Unexhausted Manure-value of Cattle Foods*"—in our paper in the last number of the Journal, for further comments and arguments on the subject. It will suffice to state here, that the rule is to deduct one-half of the *original manure-value* of the food used the last year, and one-third of the remainder each year to the eighth, in the case of all the more concentrated foods, and the roots; in fact of all the foods in the list excepting the hays and the straws; and for these, which contain larger amounts of indigestible matter, and the constituents of which will be more slowly available to crops, two-thirds of the *original manure-value* is deducted for the last year, and only one-fifth from year to year to the eighth year back.

The results of the estimates of *compensation-value* so made, are given for the five yields of 6, 8, 10, 12, and 14 quarts of milk per head per day respectively, in the five Tables—IV., V., VI., VII., and VIII. (pp. 12–16). In each case, the first column shows the *total or original manure-value* of the food; the second the allowance for the last year, the succeeding seven columns that for each year back to the eighth; and the last column gives the *total compensation-value* for eight years' consumption.

The estimates are thus fully given for a minimum yield of 6, and for a maximum of 14, quarts per head per day; also for the three intermediate amounts of 8, 10 and 12 quarts. The range of the results will, therefore, probably cover all the requirements of valuation in actual practice. It may be added, that amounts intermediate between any two of those provided for in the tables may be obtained by taking the mean of the two.

Although we have thus, in the five Tables IV. to VIII., adopted the same scale of reduction from the *total or original* manure-value from year to year, when food is consumed for the production of milk, as when the consumption is for fattening increase, it must be borne in mind that, when cows are fed in sheds or yards, the manure is generally liable to greater losses than is the case with fattening oxen. The manure from the cow contains much more water in proportion to solid matter than that of the ox. Water will, besides, frequently be used

[*continued on p.* 17

TABLE IV.—*Estimates of the Compensation-value of the Unexhausted Manure when Foods are consumed for the Production of Milk, starting from the Tota or Original Manure-value.*

1. Assuming a yield of 6 quarts of milk per head per day.

Foods	Total or original manure-value, deducting constituents in milk only	Compensation-value of unexhausted manures								Total
		Last year	Second year	Third year	Fourth year	Fifth year	Sixth year	S'v'nth year	Eighth year	
DEDUCT ½ OF ORIGINAL MANURE-VALUE THE LAST YEAR, AND ⅛ FROM YEAR TO YEAR										
One Ton	£ s. d.	£ s. d.	£ s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	£ s. d
1. Linseed	1 14 7	0 17 4	0 11 7	7 9	5 2	3 5	2 3	1 6	1 0	2 10
2. Linseed cake	2 8 1	1 4 1	0 16 1	10 9	7 2	4 9	3 2	2 1	1 5	3 9
3 Decorticated cotton cake	3 11 2	1 15 7	1 3 9	15 10	10 7	7 1	4 9	3 2	2 1	5 2
4. Palm-nut cake	1 3 2	0 11 7	0 7 9	5 2	3 5	2 3	1 6	1 0	0 8	1 13
5 Undecorticat'd cotton cake	2 2 4	1 1 2	0 14 1	9 5	6 3	4 2	2 9	1 10	1 3	3 0
6. Cocoa-nut cake	1 16 11	0 18 6	0 12 4	8 3	5 6	3 8	2 5	1 7	1 1	2 13
7. Rape cake	2 14 2	1 7 1	0 18 1	12 1	8 1	5 5	3 7	2 5	1 7	3 18
8. Peas	1 13 1	0 16 7	0 11 1	7 5	4 11	3 3	2 2	1 5	0 11	2 7
9. Beans	1 18 7	0 19 4	0 12 11	8 7	5 9	3 10	2 7	1 9	1 2	2 15
10. Lentils	1 17 5	0 18 9	0 12 6	8 4	5 7	3 9	2 6	1 8	1 1	2 14
11. Tares (seed)	1 17 11	0 19 0	0 12 8	8 5	5 7	3 9	2 6	1 8	1 1	2 14
12. Indian corn	0 13 4	0 6 8	0 4 5	2 11	1 11	1 3	0 10	0 7	0 5	0 19
13. Wheat	0 15 8	0 7 10	0 5 3	3 6	2 4	1 7	1 1	0 9	0 6	1 2
14. Malt	0 14 5	0 7 3	0 4 10	3 3	2 2	1 5	0 11	0 7	0 5	1 0
15. Barley	0 14 0	0 7 0	0 4 8	3 1	2 1	1 5	0 11	0 7	0 5	1 0
16. Oats	0 16 8	0 8 4	0 5 7	3 9	2 6	1 8	1 1	0 9	0 6	1 4
17. Rice meal	0 15 5	0 7 9	0 5 2	3 5	2 3	1 6	1 0	0 8	0 5	1 2
18. Locust beans	—	—	—	—	—	—	—	—	—	—
19. Malt coombs	2 3 9	1 1 11	0 14 7	9 9	6 6	4 4	2 11	1 11	1 3	3 3
20. Fine pollard	1 12 0	0 16 0	0 10 8	7 1	4 9	3 2	2 1	1 5	0 11	2 6
21. Coarse pollard	1 15 2	0 17 7	0 11 9	7 10	5 3	3 6	2 4	1 7	1 1	2 10
22. Bran	1 15 11	0 18 0	0 12 0	8 0	5 4	3 7	2 5	1 7	1 1	2 12
DEDUCT ⅛ OF ORIGINAL MANURE-VALUE THE LAST YEAR, AND ⅕ FROM YEAR TO YEAR										
One Ton										
23. Clover hay	1 5 5	0 8 6	0 6 10	5 6	4 5	3 6	2 10	2 3	1 10	1 15
24. Meadow hay	0 17 0	0 5 8	0 4 6	3 7	2 10	2 3	1 10	1 6	1 2	1 3
25. Pea straw	0 10 9	0 3 7	0 2 10	2 3	1 10	1 6	1 2	0 11	0 9	0 14
26. Oat straw	0 6 2	0 2 1	0 1 8	1 4	1 1	0 10	0 8	0 6	0 5	0 8
27. Wheat straw	0 5 5	0 1 10	0 1 6	1 2	0 11	0 9	0 7	0 6	0 5	0 7
28. Barley straw	0 5 6	0 1 10	0 1 6	1 2	0 11	0 9	0 7	0 6	0 5	0 7
29. Bean straw	0 10 4	0 3 5	0 2 9	2 2	1 9	1 5	1 2	0 11	0 9	0 14
DEDUCT ½ OF ORIGINAL MANURE-VALUE THE LAST YEAR, AND ⅛ FROM YEAR TO YEAR										
Ten Tons										
30. Potatoes	1 17 6	0 18 9	0 12 6	8 4	5 7	3 9	2 6	1 8	1 1	2 14
31. Carrots	1 5 0	0 12 6	0 8 4	5 7	3 9	2 6	1 8	1 1	0 9	1 16
32. Parsnips	1 12 6	0 16 3	0 10 10	7 3	4 10	3 3	2 2	1 5	0 11	2 6
33. Mangel wurzels	1 10 0	0 15 0	0 10 0	6 8	4 5	2 11	1 11	1 3	0 10	2 3
34. Swedish turnips	1 7 6	0 13 9	0 9 2	6 1	4 1	2 9	1 10	1 3	0 10	1 19
35. Yellow turnips	1 3 4	0 11 8	0 7 9	5 2	3 5	2 3	1 6	1 0	0 8	1 13
36. White turnips	1 4 2	0 12 1	0 8 1	5 5	3 7	2 5	1 7	1 1	0 9	1 15

TABLE V.—*Estimates of the Compensation-value of the Unexhausted Manures when Foods are consumed for the Production of Milk, starting from the Total or Original Manure-value.*

2. Assuming a yield of 8 quarts of milk per head per day.

Foods	Total or original manure-value, deducting constituents in milk only	Compensation-value of unexhausted manures: Last year	Second year	Third year	Fourth year	Fifth year	Sixth year	S'v'nth year	Eighth year	Total
DEDUCT ¼ OF ORIGINAL MANURE-VALUE THE LAST YEAR, AND ⅛ FROM YEAR TO YEAR										
One Ton	£ s. d.	£ s. d.	£ s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	£ s. d.
1. Linseed	1 12 0	0 16 0	0 10 8	7 1	4 9	3 2	2 1	1 5	0 11	2 6 1
2. Linseed cake	2 6 0	1 3 0	0 15 4	10 3	6 10	4 7	3 1	2 1	1 5	3 6 7
3. Decorticated cotton cake	3 9 2	1 14 7	1 3 1	15 5	10 3	6 10	4 7	3 1	2 1	4 19 11
4. Palm-nut cake	1 1 4	0 10 8	0 7 1	4 9	3 2	2 1	1 5	0 11	0 7	1 10 8
5. Undecortic't'd cotton cake	2 0 8	1 0 4	0 13 7	9 1	6 1	4 1	2 9	1 10	1 3	2 19 0
6. Cocoa-nut cake	1 15 3	0 17 8	0 11 9	7 10	5 3	3 6	2 4	1 7	1 1	2 11 0
7. Rape cake	2 12 11	1 6 6	0 17 8	11 9	7 10	5 3	3 6	2 4	1 7	3 16 5
8. Peas	1 11 2	0 15 7	0 10 5	6 11	4 7	3 1	2 1	1 5	0 11	2 5 0
9. Beans	1 16 10	0 18 5	0 12 3	8 2	5 5	3 7	2 5	1 7	1 1	2 12 11
10. Lentils	1 15 7	0 17 10	0 11 11	7 11	5 3	3 6	2 4	1 7	1 1	2 11 5
11. Tares (seed)	1 16 0	0 18 0	0 12 0	8 0	5 4	3 7	2 5	1 7	1 1	2 12 0
12. Indian corn	0 11 7	0 5 10	0 3 11	2 7	1 9	1 2	0 9	0 6	0 4	0 16 10
13. Wheat	0 13 11	0 7 0	0 4 8	3 1	2 1	1 5	0 11	0 7	0 5	1 0 2
14. Malt	0 12 7	0 6 4	0 4 3	2 10	1 11	1 3	0 10	0 7	0 5	0 18 5
15. Barley	0 12 3	0 6 2	0 4 1	2 9	1 10	1 3	0 10	0 7	0 5	0 17 11
16. Oats	0 15 0	0 7 6	0 5 0	3 4	2 3	1 6	1 0	0 8	0 5	1 1 8
17. Rice meal	0 13 9	0 6 11	0 4 7	3 1	2 1	1 5	0 11	0 7	0 5	1 0 0
18. Locust beans	—	—	—	—	—	—	—	—	—	—
19. Malt coombs	2 2 0	1 1 0	0 14 0	9 4	6 3	4 2	2 9	1 10	1 3	3 0 7
20. Fine pollard	1 10 5	0 15 3	0 10 2	6 9	4 6	3 0	2 0	1 4	0 11	2 3 11
21. Coarse pollard	1 13 6	0 16 9	0 11 2	7 5	4 11	3 3	2 2	1 5	0 11	2 8 0
22. Bran	1 14 6	0 17 3	0 11 6	7 8	5 1	3 5	2 3	1 6	1 0	2 9 8
DEDUCT ⅓ OF ORIGINAL MANURE-VALUE THE LAST YEAR, AND ⅛ FROM YEAR TO YEAR										
One Ton										
23. Clover hay	1 4 5	0 8 2	0 6 6	5 2	4 2	3 4	2 8	2 2	1 9	1 13 11
24. Meadow hay	0 16 3	0 5 5	0 4 4	3 6	2 10	2 3	1 10	1 6	1 2	1 2 10
25. Pea straw	0 10 0	0 3 4	0 2 8	2 2	1 9	1 5	1 2	0 11	0 9	0 14 2
26. Oat straw	0 5 5	0 1 10	0 1 6	1 2	0 11	0 9	0 7	0 6	0 5	0 7 8
27. Wheat straw	0 4 10	0 1 7	0 1 3	1 0	0 10	0 8	0 6	0 5	0 4	0 6 7
28. Barley straw	0 4 10	0 1 7	0 1 3	1 0	0 10	0 8	0 6	0 5	0 4	0 6 7
29. Bean straw	0 9 9	0 3 3	0 2 7	2 1	1 8	1 4	1 1	0 10	0 8	0 13 6
DEDUCT ¼ OF ORIGINAL MANURE-VALUE THE LAST YEAR, AND ⅛ FROM YEAR TO YEAR										
Ten Tons										
30. Potatoes	1 15 0	0 17 6	0 11 8	7 9	5 2	3 5	2 3	1 6	1 0	2 10 3
31. Carrots	1 3 4	0 11 8	0 7 9	5 2	3 5	2 3	1 6	1 0	0 8	1 13 5
32. Parsnips	1 10 10	0 15 5	0 10 3	6 10	4 7	3 1	2 1	1 5	0 11	2 4 7
33. Mangel wurzels	1 8 4	0 14 2	0 9 5	6 3	4 2	2 9	1 10	1 3	0 10	2 0 8
34. Swedish turnips	1 6 8	0 13 4	0 8 11	5 11	3 11	2 7	1 9	1 2	0 9	1 18 4
35. Yellow turnips	1 2 6	0 11 3	0 7 6	5 0	3 4	2 3	1 6	1 0	0 8	1 12 6
36. White turnips	1 3 4	0 11 8	0 7 9	5 2	3 5	2 3	1 6	1 0	0 8	1 13 5

TABLE VI.—*Estimates of the Compensation-value of the Unexhausted Manure which Foods are consumed for the Production of Milk, starting from the Point of Least Manurial Value.*

1. Assuming a yield of 12 quarts of milk per head per day.

Food	Value of Foods consumed per head per day	Compensation-value of unexhausted manures								Total
		Last year	Second year	Third year	Fourth year	Fifth year	Sixth year	Seventh year	Eighth year	
Foods of Small Manurial Value, Last Year, and ¼ from Year to Year										
	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
				6 7 4	5 2 11	1 11 1	1 3 0	10		2 2 2
				4 5 9	6 6 4	4 2 11	1 11 1	1 3		3 3 2
			2 5 14	11 9 11	6 7 4	5 2 11	1 11 1			4 16 9
			6 6 4	4 2 11	1 11 1	1 3 0	10 0 7			1 8 1
			2 5 9	5 10 3	11 2 7	1 9 1	2			2 16 8
			3 7 6	5 0 3	4 2 3	1 6 1	0			2 8 9
			3 11 6	7 8 5	1 3 5	2 3 1	6			3 14 6
			6 7 4	5 2 11	1 11 1	3 0	10			2 2 6
			4 9 5	2 3 5	2 3 1	6 1	0			2 10 3
			3 6 5	0 3 4	2 3 1	6 1	0			2 8 9
			3 7 5	1 3 5	2 3 1	6 1	0			2 9 4
			2 3 6	1 0 0	8 0	5 0	3			0 14 5
			4 1 10	1 3 0	10 0	7 0	5			0 17 10
			3 6 1	1 1 0	9 0	6 0	4			0 15 7
			3 5 6	1 1 0	9 0	6 0	4			0 15 4
			4 2 11	1 3 0	10 0	7 0	5			0 19 0
			3 1 4	1 2 0	9 0	6 0	4			0 17 2
			—	—	—	—	—	—	—	—
			3 5 6	6 4 0	2 8	1 9	1 2			2 18 4
			4 3 6	3 2 10	1 11	1 3	0 10			2 1 5
			3 5 8	9 3 2	2 1	1 5	0 11			2 6 1
			3 5 4	2 3 2	2 1	5 0	11			2 7 9
Foods of Medium Manurial Value, Last Year, and ¼ from Year to Year										
			1 6 3	3 1 4	6 3 2	2 6 2	0 1	7		1 12 4
			3 4 1	6 5 4	2 5 2	2 1 9	1 5 1	2		1 1 10
			4 7 4	2 3 1	0 0 10	0 5	0	8		0 12 11
					0 6 0	5 0	4			0 6 7
					0 6 0	5 0	4			0 6 1
					0 6 0	5 0	4			0 6 1
			4 7 4	2 3 1	0 0 10	0 0	8			0 12 11
Foods of Large Manurial Value, Last Year, and ¼ from Year to Year										
			1 7 5	3 3 2	2 1 5	0 11				2 6 11
			1 6 3	2 2 1	6 1 0	0 8				1 12 6
			1 6 3	2 3 1	10 1 3	0 10				2 0 8
			1 6 3	2 3 1	10 1 3	0 10				1 19 9
			1 6 3	2 3 1	9 1 2	0 9				1 17 4
			1 6 3	2 2 1	5 0 11	0 7				1 11 3
			1 6 3	2 3 1	6 1 0	0 8				1 12 6

TABLE VII.—*Estimates of the Compensation-value of the Unexhausted Manures when Foods are consumed for the Production of Milk, starting from the Total or Original Manure-value.*

4. Assuming a yield of 12 quarts of milk per head per day.

Foods	Total or original manure-value, deducting constituents in milk only	Compensation-value of unexhausted manures								Total
		Last year	Second year	Third year	Fourth year	Fifth year	Sixth year	S'v'nth year	Eighth year	
DEDUCT ½ OF ORIGINAL MANURE-VALUE THE LAST YEAR, AND ¼ FROM YEAR TO YEAR										
One Ton	£ s. d.	£ s. d.	£ s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	£ s. d.
1. Linseed	1 7 1	0 13 7	0 9 1	6 1	4 1	2 9	1 10	1 3	0 10	1 19 6
2. Linseed cake	2 1 9	1 0 11	0 13 11	9 3	6 2	4 1	2 9	1 10	1 3	3 0 2
3. Decorticated cotton cake	3 5 4	1 12 8	1 1 9	14 6	9 8	6 5	4 3	2 10	1 11	4 14 0
4. Palm-nut cake	0 17 9	0 8 11	0 5 11	3 11	2 7	1 9	1 2	0 9	0 6	1 5 6
5. Undecortic't'd cotton cake	1 17 6	0 18 9	0 12 6	8 4	5 7	3 9	2 6	1 8	1 1	2 14 2
6. Cocoa-nut cake	1 12 3	0 16 2	0 10 9	7 2	4 9	3 2	2 1	1 5	0 11	2 6 5
7. Rape cake	2 10 4	1 5 2	0 16 9	11 2	7 5	4 11	3 3	2 2	1 5	3 12 3
8. Peas	1 7 8	0 13 10	0 9 3	6 2	4 1	2 9	1 10	1 3	0 10	2 0 0
9. Beans	1 13 1	0 16 7	0 11 1	7 5	4 11	3 3	2 2	1 5	0 11	2 7 9
10. Lentils	1 12 2	0 16 1	0 10 9	7 2	4 9	3 2	2 1	1 5	0 11	2 6 4
11. Tares (seed)	1 12 6	0 16 3	0 10 10	7 3	4 10	3 3	2 2	1 5	0 11	2 6 11
12. Indian corn	0 8 1	0 4 1	0 2 9	1 10	1 3	0 10	0 7	0 5	0 3	0 12 0
13. Wheat	0 10 5	0 5 3	0 3 6	2 4	1 7	1 1	0 9	0 6	0 4	0 15 4
14. Malt	0 9 0	0 4 6	0 3 0	2 0	1 4	0 11	0 7	0 5	0 3	0 13 0
15. Barley	0 8 8	0 4 4	0 2 11	1 11	1 3	0 10	0 7	0 5	0 3	0 12 6
16. Oats	0 11 7	0 5 10	0 3 11	2 7	1 9	1 2	0 9	0 6	0 4	0 16 10
17. Rice meal	0 10 5	0 5 3	0 3 6	2 4	1 7	1 1	0 9	0 6	0 4	0 15 4
18. Locust beans	—	—	—	—	—	—	—	—	—	—
19. Malt coombs	1 18 11	0 19 6	0 13 0	8 8	5 9	3 10	2 7	1 9	1 2	2 16 3
20. Fine pollard	1 6 11	0 13 6	0 9 0	6 0	4 0	2 8	1 9	1 2	0 9	1 18 10
21. Coarse pollard	1 10 5	0 15 3	0 10 2	6 9	4 6	3 0	2 0	1 4	0 11	2 3 11
22. Bran	1 11 8	0 15 10	0 10 7	7 1	4 9	3 2	2 1	1 5	0 11	2 5 10
DEDUCT ¾ OF ORIGINAL MANURE-VALUE THE LAST YEAR, AND ½ FROM YEAR TO YEAR										
One Ton										
23. Clover hay	1 2 8	0 7 7	0 6 1	4 10	3 10	3 1	2 6	2 0	1 7	1 11 6
24. Meadow hay	0 14 5	0 4 10	0 3 10	3 1	2 6	2 0	1 7	1 3	1 0	1 0 1
25. Pea straw	0 8 5	0 2 10	0 2 3	1 10	1 6	1 2	0 11	0 9	0 7	0 11 10
26. Oat straw	0 4 0	0 1 4	0 1 1	0 10	0 8	0 6	0 5	0 4	0 3	0 5 5
27. Wheat straw	0 3 6	0 1 2	0 0 11	0 9	0 7	0 6	0 5	0 4	0 3	0 4 11
28. Barley straw	0 3 9	0 1 3	0 1 0	0 10	0 8	0 6	0 5	0 4	0 3	0 5 3
29. Bean straw	0 8 7	0 2 10	0 2 3	1 10	1 6	1 2	0 11	0 9	0 7	0 11 10
DEDUCT ½ OF ORIGINAL MANURE-VALUE THE LAST YEAR, AND ¼ FROM YEAR TO YEAR										
Ten Tons										
30. Potatoes	1 10 10	0 15 5	0 10 3	6 10	4 7	3 1	2 1	1 5	0 11	2 4 7
31. Carrots	1 0 10	0 10 5	0 6 11	4 7	3 1	2 1	1 5	0 11	0 7	1 10 0
32. Parsnips	1 6 8	0 13 4	0 8 11	5 11	3 11	2 7	1 9	1 2	0 9	1 18 4
33. Mangel wurzels	1 5 10	0 12 11	0 8 7	5 9	3 10	2 7	1 9	1 2	0 9	1 17 4
34. Swedish turnips	1 4 2	0 12 1	0 8 1	5 5	3 7	2 5	1 7	1 1	0 9	1 15 0
35. Yellow turnips	1 0 10	0 10 5	0 6 11	4 7	3 1	2 1	1 5	0 11	0 7	1 10 0
36. White turnips	1 1 8	0 10 10	0 7 3	4 10	3 3	2 2	1 5	0 11	0 7	1 11 3

TABLE VI.—*Estimates of the Compensation-value of the Unexhausted Manures when Foods are consumed for the Production of Milk, starting from the Total or Original Manure-value.*

3. Assuming a yield of 10 quarts of milk per head per day.

Foods	Total or original manure-value, deducting constituents in milk only	Compensation-value of unexhausted manures																Total		
		Last year			Second year			Third year		Fourth year		Fifth year		Sixth year		S'v'nth year		Eighth year		
DEDUCT ½ OF ORIGINAL MANURE-VALUE THE LAST YEAR, AND ⅛ FROM YEAR TO YEAR																				
One Ton	£ s. d.	£	s.	d.	£	s.	d.	s.	d.	s.	d.	s.	d.	s.	d.	s.	d.	s.	d.	£ s. d.
1. Linseed	1 9 6	0	14	9	0	9	10	6	7	4	5	2	11	1	11	1	3	0	10	2 2 2
2. Linseed cake	2 3 10	1	1	11	0	14	7	9	9	6	6	4	4	2	11	1	11	1	3	3 3 2
3. Decorticated cotton cake	3 7 4	1	13	8	1	2	5	14	11	9	11	6	7	4	5	2	11	1	11	4 16 9
4. Palm-nut cake	0 19 5	0	9	9	0	6	6	4	4	2	11	1	11	1	3	0	10	0	7	1 8 1
5. Undecortic't'd cotton cake	1 19 2	0	19	7	0	13	1	8	9	5	10	3	11	2	7	1	9	1	2	2 16 8
6. Cocoa-nut cake	1 13 9	0	16	11	0	11	3	7	6	5	0	3	4	2	3	1	6	1	0	2 8 9
7. Rape cake	2 11 7	1	5	10	0	17	3	11	6	7	8	5	1	3	5	2	3	1	6	3 14 6
8. Peas	1 9 6	0	14	9	0	9	10	6	7	4	5	2	11	1	11	1	3	0	10	2 2 6
9. Beans	1 14 11	0	17	6	0	11	8	7	9	5	2	3	5	2	3	1	6	1	0	2 10 3
10. Lentils	1 13 9	0	16	11	0	11	3	7	6	5	0	3	4	2	3	1	6	1	0	2 8 9
11. Tares (seed)	1 14 2	0	17	1	0	11	5	7	7	5	1	3	5	2	3	1	6	1	0	2 9 4
12. Indian corn	0 9 11	0	5	0	0	3	4	2	3	1	6	1	0	0	8	0	5	0	3	0 14 5
13. Wheat	0 12 1	0	6	1	0	4	1	2	9	1	10	1	3	0	10	0	7	0	5	0 17 10
14. Malt	0 10 8	0	5	4	0	3	7	2	5	1	7	1	1	0	9	0	6	0	4	0 15 7
15. Barley	0 10 6	0	5	3	0	3	6	2	4	1	7	1	1	0	9	0	6	0	4	0 15 4
16. Oats	0 13 4	0	6	8	0	4	5	2	11	1	11	1	3	0	10	0	7	0	5	0 19 0
17. Rice meal	0 12 0	0	6	0	0	4	0	2	8	1	9	1	2	0	9	0	6	0	4	0 17 2
18. Locust beans	—	—			—			—		—		—		—		—		—		—
19. Malt coombs	2 0 6	1	0	3	0	13	6	9	0	6	0	4	0	2	8	1	9	1	2	2 18 4
20. Fine pollard	1 8 8	0	14	4	0	9	7	6	5	4	3	2	10	1	11	1	3	0	10	2 1 5
21. Coarse pollard	1 12 0	0	16	0	0	10	8	7	1	4	9	3	2	2	1	1	5	0	11	2 6 1
22. Bran	1 13 1	0	16	7	0	11	1	7	5	4	11	3	3	2	2	1	5	0	11	2 7 9
DEDUCT ¾ OF ORIGINAL MANURE-VALUE THE LAST YEAR, AND ¼ FROM YEAR TO YEAR																				
One Ton																				
23. Clover hay	1 3 7	0	7	10	0	6	3	5	0	4	0	3	2	2	6	2	0	1	7	1 12 4
24. Meadow hay	0 15 5	0	5	2	0	4	2	3	4	2	8	2	2	1	9	1	5	1	2	1 1 10
25. Pea straw	0 9 3	0	3	1	0	2	6	2	0	1	7	1	3	1	0	0	10	0	8	0 12 11
26. Oat straw	0 4 9	0	1	7	0	1	3	1	0	0	10	0	8	0	6	0	5	0	4	0 6 7
27. Wheat straw	0 4 2	0	1	5	0	1	2	0	11	0	9	0	7	0	6	0	5	0	4	0 6 1
28. Barley straw	0 4 4	0	1	5	0	1	2	0	11	0	9	0	7	0	6	0	5	0	4	0 6 1
29. Bean straw	0 9 2	0	3	1	0	2	6	2	0	1	7	1	3	1	0	0	10	0	8	0 12 11
DEDUCT ½ OF ORIGINAL MANURE-VALUE THE LAST YEAR, AND ⅛ FROM YEAR TO YEAR																				
Ten Tons																				
30. Potatoes	1 12 6	0	16	3	0	10	10	7	3	4	10	3	3	2	2	1	5	0	11	2 6 11
31. Carrots	1 2 6	0	11	3	0	7	6	5	0	3	4	2	3	1	6	1	0	0	8	1 12 6
32. Parsnips	1 8 4	0	14	2	0	9	5	6	3	4	2	2	9	1	10	1	3	0	10	2 0 8
33. Mangel wurzels	1 7 6	0	13	9	0	9	2	6	1	4	1	2	9	1	10	1	3	0	10	1 19 9
34. Swedish turnips	1 5 10	0	12	11	0	8	7	5	9	3	10	2	7	1	9	1	2	0	9	1 17 4
35. Yellow turnips	1 1 8	0	10	10	0	7	3	4	10	3	3	2	2	1	5	0	11	0	7	1 11 3
6. White turnips	1 2 6	0	11	3	0	7	6	5	0	3	4	2	3	1	6	1	0	0	8	1 12 6

TABLE VII.—*Estimates of the Compensation-value of the Unexhausted Manures when Foods are consumed for the Production of Milk, starting from the Total or Original Manure-value.*

4. Assuming a yield of 12 quarts of milk per head per day.

Foods	Total or original manure-value, deducting constituents in milk only	Compensation-value of unexhausted manures: Last year	Second year	Third year	Fourth year	Fifth year	Sixth year	S'v'nth year	Eighth year	Total
DEDUCT ½ OF ORIGINAL MANURE-VALUE THE LAST YEAR, AND ¼ FROM YEAR TO YEAR										
One Ton	£ s. d.	£ s. d.	£ s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	£ s. d.
1. Linseed	1 7 1	0 13 7	0 9 1	6 1	4 1	2 9	1 10	1 3	0 10	1 19 6
2. Linseed cake	2 1 9	1 0 11	0 13 11	9 3	6 2	4 1	2 9	1 10	1 3	3 0 2
3. Decorticated cotton cake	3 5 4	1 12 8	1 1 9	14 6	9 8	6 5	4 3	2 10	1 11	4 14 0
4. Palm-nut cake	0 17 9	0 8 11	0 5 11	3 11	2 7	1 9	1 2	0 9	0 6	1 5 6
5. Undecortic't'd cotton cake	1 17 6	0 18 9	0 12 6	8 4	5 7	3 9	2 6	1 8	1 1	2 14 2
6. Cocoa-nut cake	1 12 3	0 16 2	0 10 9	7 2	4 9	3 2	2 1	1 5	0 11	2 6 5
7. Rape cake	2 10 4	1 5 2	0 16 9	11 2	7 5	4 11	3 3	2 2	1 5	3 12 3
8. Peas	1 7 8	0 13 10	0 9 3	6 2	4 1	2 9	1 10	1 3	0 10	2 0 0
9. Beans	1 13 1	0 16 7	0 11 1	7 5	4 11	3 3	2 2	1 5	0 11	2 7 9
10. Lentils	1 12 2	0 16 1	0 10 9	7 2	4 9	3 2	2 1	1 5	0 11	2 6 4
11. Tares (seed)	1 12 6	0 16 3	0 10 10	7 3	4 10	3 3	2 2	1 5	0 11	2 6 11
12. Indian corn	0 8 1	0 4 1	0 2 9	1 10	1 3	0 10	0 7	0 5	0 3	0 12 0
13. Wheat	0 10 5	0 5 3	0 3 6	2 4	1 7	1 1	0 9	0 6	0 4	0 15 4
14. Malt	0 9 0	0 4 6	0 3 0	2 0	1 4	0 11	0 7	0 5	0 3	0 13 0
15. Barley	0 8 8	0 4 4	0 2 11	1 11	1 3	0 10	0 7	0 5	0 3	0 12 6
16. Oats	0 11 7	0 5 10	0 3 11	2 7	1 9	1 2	0 9	0 6	0 4	0 16 10
17. Rice meal	0 10 5	0 5 3	0 3 6	2 4	1 7	1 1	0 9	0 6	0 4	0 15 4
18. Locust beans	—	—	—	—	—	—	—	—	—	—
19. Malt coombs	1 18 11	0 19 6	0 13 0	8 8	5 9	3 10	2 7	1 9	1 2	2 16 3
20. Fine pollard	1 6 11	0 13 6	0 9 0	6 0	4 0	2 8	1 9	1 2	0 9	1 18 10
21. Coarse pollard	1 10 5	0 15 3	0 10 2	6 9	4 6	3 0	2 0	1 4	0 11	2 3 11
22. Bran	1 11 8	0 15 10	0 10 7	7 1	4 9	3 2	2 1	1 5	0 11	2 5 10
DEDUCT ¼ OF ORIGINAL MANURE-VALUE THE LAST YEAR, AND ⅕ FROM YEAR TO YEAR										
One Ton										
23. Clover hay	1 2 8	0 7 7	0 6 1	4 10	3 10	3 1	2 6	2 0	1 7	1 11 6
24. Meadow hay	0 14 5	0 4 10	0 3 10	3 1	2 6	2 0	1 7	1 3	1 0	1 0 1
25. Pea straw	0 8 5	0 2 10	0 2 3	1 10	1 6	1 2	0 11	0 9	0 7	0 11 10
26. Oat straw	0 4 0	0 1 4	0 1 1	0 10	0 8	0 6	0 5	0 4	0 3	0 5 5
27. Wheat straw	0 3 6	0 1 2	0 0 11	0 9	0 7	0 6	0 5	0 4	0 3	0 4 11
28. Barley straw	0 3 9	0 1 3	0 1 0	0 10	0 8	0 6	0 5	0 4	0 3	0 5 3
29. Bean straw	0 8 7	0 2 10	0 2 3	1 10	1 6	1 2	0 11	0 9	0 7	0 11 10
DEDUCT ½ OF ORIGINAL MANURE-VALUE THE LAST YEAR, AND ¼ FROM YEAR TO YEAR										
Ten Tons										
30. Potatoes	1 10 10	0 15 5	0 10 3	6 10	4 7	3 1	2 1	1 5	0 11	2 4 7
31. Carrots	1 0 10	0 10 5	0 6 11	4 7	3 1	2 1	1 5	0 11	0 7	1 10 0
32. Parsnips	1 6 8	0 13 4	0 8 11	5 11	3 11	2 7	1 9	1 2	0 9	1 18 4
33. Mangel wurzels	1 5 10	0 12 11	0 8 7	5 9	3 10	2 7	1 9	1 2	0 9	1 17 4
34. Swedish turnips	1 4 2	0 12 1	0 8 1	5 5	3 7	2 5	1 7	1 1	0 9	1 15 0
35. Yellow turnips	1 0 10	0 10 5	0 6 11	4 7	3 1	2 1	1 5	0 11	0 7	1 10 0
36. White turnips	1 1 8	0 10 10	0 7 3	4 10	3 3	2 2	1 5	0 11	0 7	1 11 3

TABLE VIII.—*Estimates of the Compensation-value of the Unexhausted Manures when Foods are consumed for the Production of Milk, starting from the Total or Original Manure-value.*

5. Assuming a yield of 14 quarts of milk per head per day.

Foods	Total or original manure-value, deducting constituents in milk only	Compensation-value of unexhausted manures																Total		
		Last year			Second year			Third year		Fourth year		Fifth year		Sixth year		S'v'nth year		Eighth year		
DEDUCT ½ OF ORIGINAL MANURE-VALUE THE LAST YEAR, AND ¼ FROM YEAR TO YEAR																				
One Ton	£ s. d.	£	s.	d.	£	s.	d.	s.	d.	s.	d.	s.	d.	s.	d.	s.	d.	£	s.	d.
1. Linseed	1 4 5	0	12	3	0	8	2	5	5	3	7	2	5	1	7	1	1	0	9	1	15	3
2. Linseed cake	1 19 8	0	19	10	0	13	3	8	10	5	11	3	11	2	7	1	9	1	2	2	17	3
3 { Decorticated cotton cake }	3 3 4	1	11	8	1	1	1	14	1	9	5	6	3	4	2	2	9	1	10	4	11	3
4. Palm-nut cake	0 15 11	0	8	0	0	5	4	3	7	2	5	1	7	1	1	0	9	0	6	1	3	3
5 { Undecortic't'd cotton cake }	1 15 11	0	18	0	0	12	0	8	0	5	4	3	7	2	5	1	7	1	1	2	12	0
6. Cocoa-nut cake	1 10 6	0	15	3	0	10	2	6	9	4	6	3	0	2	0	1	4	0	11	2	3	11
7. Rape cake	2 9 1	1	4	7	0	16	5	10	11	7	3	4	10	3	3	2	2	1	5	3	10	10
8. Peas	1 5 9	0	12	11	0	8	7	5	9	3	10	2	7	1	9	1	2	0	9	1	17	4
9. Beans	1 11 4	0	15	8	0	10	5	6	11	4	7	3	1	2	1	1	5	0	11	2	5	1
10. Lentils	1 10 1	0	15	1	0	10	1	6	9	4	6	3	0	2	0	1	4	0	11	2	3	8
11. Tares (seed)	1 10 7	0	15	4	0	10	3	6	10	4	7	3	1	2	1	1	5	0	11	2	4	6
12. Indian corn	0 6 5	0	3	3	0	2	2	1	5	0	11	0	7	0	5	0	3	0	2	0	9	2
13. Wheat	0 8 8	0	4	4	0	2	11	1	11	1	3	0	10	0	7	0	5	0	3	0	12	6
14. Malt	0 7 1	0	3	7	0	2	5	1	7	1	1	0	9	0	6	0	4	0	3	0	10	6
15. Barley	0 6 11	0	3	6	0	2	4	1	7	1	1	0	9	0	6	0	4	0	3	0	10	4
16. Oats	0 9 10	0	4	11	0	3	3	2	2	1	5	0	11	0	7	0	5	0	3	0	13	11
17. Rice meal	0 8 7	0	4	4	0	2	11	1	11	1	3	0	10	0	7	0	5	0	3	0	12	6
18. Locust beans	—		—			—		—		—		--		—		—		—		
19. Malt coombs	1 17 4	0	18	8	0	12	5	8	3	5	6	3	8	2	5	1	7	1	1	2	13	7
20. Fine pollard	1 5 3	0	12	8	0	8	5	5	7	3	9	2	6	1	8	1	1	0	9	1	16	8
21. Coarse pollard	1 8 9	0	14	5	0	9	7	6	5	4	3	2	10	1	11	1	3	0	10	2	1	6
22. Bran	1 10 3	0	15	2	0	10	1	6	9	4	6	3	0	2	0	1	4	0	11	2	3	9
DEDUCT ⅓ OF ORIGINAL MANURE-VALUE THE LAST YEAR, AND ⅕ FROM YEAR TO YEAR																				
One Ton																				
23. Clover hay	1 1 8	0	7	3	0	5	10	4	8	3	10	3	1	2	6	2	0	1	7	1	10	9
24. Meadow hay	0 13 7	0	4	6	0	3	7	2	10	2	3	1	10	1	6	1	2	0	11	0	18	7
25. Pea straw	0 7 8	0	2	7	0	2	1	1	8	1	4	1	1	0	10	0	8	0	6	0	10	9
26. Oat straw	0 3 3	0	1	1	0	0	10	0	8	0	6	0	5	0	4	0	3	0	2	0	4	2
27. Wheat straw	0 3 0	0	1	0	0	0	10	0	8	0	6	0	5	0	4	0	3	0	2	0	4	2
28. Barley straw	0 3 2	0	1	1	0	0	10	0	8	0	6	0	5	0	4	0	3	0	2	0	4	3
29. Bean straw	0 8 0	0	2	8	0	2	2	1	9	1	5	1	2	0	11	0	9	0	7	0	11	5
DEDUCT ½ OF ORIGINAL MANURE-VALUE THE LAST YEAR, AND ¼ FROM YEAR TO YEAR																				
Ten Tons																				
30. Potatoes	1 9 2	0	14	7	0	9	9	6	6	4	4	2	11	1	11	1	3	0	10	2	2	1
31. Carrots	0 19 2	0	9	7	0	6	5	4	3	2	10	1	11	1	3	0	10	0	7	1	7	8
32. Parsnips	1 5 10	0	12	11	0	8	7	5	9	3	10	2	7	1	9	1	2	0	9	1	17	4
33. Mangel wurzels	1 4 2	0	12	1	0	8	1	5	5	3	7	2	5	1	7	1	1	0	9	1	15	0
34. Swedish turnips	1 2 6	0	11	3	0	7	6	5	0	3	4	2	3	1	6	1	0	0	8	1	12	0
35. Yellow turnips	1 0 0	0	10	0	0	6	8	4	5	2	11	1	11	1	3	0	10	0	7	1	8	[illegible]
36. White turnips	1 0 0	0	10	0	0	6	8	4	5	2	11	1	11	1	3	0	10	0	7	1	8	[illegible]

for washing, and it may be that a good deal of the manure is washed into drains and lost. In the event, therefore, of a claim for compensation, the management and disposal of the manure requires the attention of the valuer. Indeed, the varying circumstances that will arise in practice must be carefully considered. Bearing these in mind, the estimates may be accepted as at any rate the best approximation to the truth that existing knowledge enables us to provide; and they will, we hope, be found sufficient for the requirements of practical use. Obviously, they will be more directly applicable in the case of cows feeding entirely on the foods enumerated in the list, and not depending largely on grass; but even when the animals are partially grass-fed, the value of the manure derived from the additional dry food, or roots, may be estimated according to the scale given.

For any further particulars relating to the general question of the valuation of the manures obtained by the consumption of food-stuffs, we must refer to the full discussion of the subject in our paper in the last number of the Journal.

Rothamsted.

JOHN BENNET LAWES.
J. HENRY GILBERT.

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THE

GROWTH OF SUGAR BEET

AND THE

MANUFACTURE OF SUGAR

IN THE UNITED KINGDOM.

BY

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1898.

THE GROWTH OF SUGAR-BEET, AND THE MANUFACTURE OF SUGAR, IN THE UNITED KINGDOM.

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INTRODUCTION.

NEARLY thirty years ago, Mr. James Duncan established a sugar factory at Lavenham in Suffolk, and made arrangements with farmers in the locality to grow sugar-beet, for which he was to pay them about 20*s.* per ton, delivered to the factory. We believe that Mr. Duncan commenced operations in 1869, and closed his factory in 1873. From results kindly furnished to us by Messrs. Newlands Brothers, it would appear that there was considerable advance from year to year in the quality of the roots grown. Thus, the analyses of numerous lots in 1869 showed an average of 8·39 per cent. of sugar; of several lots in 1870 of 9·19 per cent.; of five lots in 1871 of 10·59 per cent.; and of twelve lots in 1872, an average of 11·84 per cent. of sugar in the roots. It may be added that among the twelve lots analysed in 1872, the lowest percentage was 8·27, and the

highest 15·15; whilst four gave over 13, two between 12 and 13, and two between 11 and 12 per cent.

Various local difficulties have been alleged as contributing to Mr. Duncan's want of success in his endeavours to establish the growth of sugar-beet, and the manufacture of sugar from it, at Lavenham; but one, if true, seems quite sufficient to account for the result, and it should be very carefully considered, and taken as a serious warning, in any future undertakings of the kind. It is said that with a requirement of at least 30,000 tons of roots to work his factory profitably, Mr. Duncan finally could only obtain about 7,000 tons. The fact appears to be, that the farmers did not sufficiently modify their rotations to secure an adequate supply of roots; and even in some cases they used for feeding purposes what they had grown, if other feed was scarce.

The question of the suitability of our climate for the production of the crop for the purposes of the manufacture, and also that of the effects of different manures on the growth of the crop and on its richness in sugar, led us to undertake some experiments at Rothamsted on the subject. As will be explained more in detail further on, the experiments were commenced in 1871 and continued for five years. In the autumn of 1871, one of us who had previously visited Mr. Duncan at Lavenham, went there to learn what progress had been made, and was kindly guided and supplied with much information by Mr. William Biddell. From Lavenham he went on to visit some of the chief sugar-beet districts in Germany, Austria, France, Belgium, and Holland; and continued the inquiry in the autumn of 1872. Full notes were taken, and a full report was written, embodying the information acquired; but, owing to the unfortunate collapse of Mr. Duncan's most laudable enterprise at Lavenham, the report was never published; and, for the same reason, the results of the Rothamsted experiments on the growth of sugar-beet by different manures, and over several seasons, attracted very little attention.

During the last few years, however, the subject of the growth of sugar-beet, and the establishment of factories for the manufacture of sugar from it, in this country, has been very much discussed; and we have been requested to write a paper on the present position of the question. At first sight, it certainly seems somewhat remarkable, that with a price in our markets of raw beetroot sugar (of 88·0 per cent. purity), of about 23*l.* 10*s.* per ton in 1870, of about 25*l.* in 1873, and of about 24*l.* in 1874, Mr. Duncan's attempt to introduce the crop and the manufacture into the country failed, and yet at the present time, with the price of sugar only about 9*l.* per ton, very sanguine expectations of the success of such an enterprise are put forward, and the scheme is strongly advocated as a means of resuscitating agricultural prosperity.

Our own early experiments were not arranged with a view to affording exact models for adoption in the growth of the crop for sugar-making, but were conducted much on the lines of our other experiments on root-crops. The results do, however, as will be seen, supply much valuable information on the effects of different manures on the quantity and on the composition of the crop, and so afford important data as to its manurial requirements. For direct application to practice in the growth of the crop for sugar-making, the amounts of nitrogenous manures used were too large, and the distances apart from plant to plant were too great; conditions leading to over-luxuriance and to imperfect maturing of the individual plants. We have, however, undertaken some experiments on a limited area in the present season; arranged more with the view of obtaining both fair luxuriance and at the same time adequate ripening, so as to ensure high percentage of sugar; and specially with a view to the latter point, we have obtained from Messrs. Vilmorin & Co., of Paris, seed of the most approved description at the present time.

The Rothamsted Experiments on Sugar-beet in 1871–5.

The experiments made at Rothamsted with sugar-beet were commenced in 1871, and continued for five years in succession to 1875 inclusive. They were conducted on the land which had been devoted to the continuous growth of root-crops (Norfolk Whites and Swedish turnips), from 1843 to 1870; excepting that in the three years 1853–5 barley was grown without manure to equalise the condition of the plots as far as possible before re-arranging them and the manuring.

During the first three of the five years of sugar-beet the

arrangement of the plots and of the manures was substantially the same as during the preceding ten years with Swedish turnips, and the subsequent years with mangel-wurzel. But during the last two years of the five, neither farmyard nor any other nitrogenous manure was applied; the object being to determine the effects of the unexhausted residue of the nitrogenous applications during the preceding three years. The description of sugar-beet grown was Vilmorin's "Green-top White Silesian." In 1871, the seed was dibbled on ridges in rows 26 inches apart, and 10 inches from plant to plant in the rows; in 1872 and subsequently it was dibbled on the flat, in rows 22½ inches apart, and 11 inches apart in the rows; the plants being moulded up afterwards. The roots were all carted off, and weighed; the leaves weighed, spread on the respective plots, and ploughed in.

Table I. (p. 7) shows, for selected plots, the manuring, the average produce over the three years, of root and of leaf, the average percentages of nitrogen, and of mineral matter, in the dry matter of the roots, and the average percentages, and amounts per acre, of sugar in the roots over the three years, 1871–3, during which the farmyard manure and the nitrogenous cross-dressings were annually applied.

It will be seen that the nitrogenous cross-dressings, which were the same as those before and subsequently adopted for feeding roots, were very heavy; indeed, much heavier than is recognised as suitable in the case of beet grown for the production of sugar. The result was that when these were used in addition to farmyard manure, the produce of roots per acre was large, in some cases about twice as much as that obtained in the growth of sugar-beet for the manufacture of sugar in Germany or France at the present time. The farmyard manure alone gave an average over the three years of 16 tons 6 cwt. of roots; and the amount was raised to 23 tons 16 cwt. by the addition of 550 lb. nitrate of soda, containing 86 lb. of nitrogen; to 22 tons 6 cwt. by 400 lb. salts of ammonia, supplying 86 lb. of nitrogen; to 24 tons 18 cwt. by 2,000 lb. of rape-cake, containing 98 lb. of nitrogen; and to 25 tons 2 cwt. by rape-cake and salts of ammonia together, supplying annually 184 lb. of nitrogen.

The Table (p. 7) shows, however, that the amount of sugar in the roots in neither case reached 12 per cent.; but it was the highest, 11·84, with the farmyard manure alone and the smallest crop, and the lowest, 9·99 per cent., with the farmyard manure and the heaviest nitrogenous cross-dressing, and the heaviest crop. The roots of the other series, with inter-

TABLE I.—*Showing the Quantity and Composition of the Produce of Sugar-beet, with Different Descriptions and Amounts of Manure.*

Plot	Standard manures	Series 1. Standard manures only	Standard manures and cross-dressings each year as under			
			Series 2. 550 lb. nitrate of soda = 86 lb. nitrogen	Series 3. 400 lb. salts of ammonia = 86 lb. nitrogen	Series 4. 400 lb. salts of ammonia & 2,000 lb. rape-cake = 184 lb. nitrogen	Series 5. 2,000 lb. rape-cake = 98 lb. nitrogen
PRODUCE OF ROOTS PER ACRE.						
		tons cwt.	tons cwt.	tons cwt.	tons cwt.	tons cwt.
1	14 tons farmyard manure .	16 6	23 16	22 6	25 2	24 18
5	Superphosphate . . .	5 18	19 11	13 9	17 15	16 5
4 & 6	Superphosphate and potash	5 18	18 17	14 19	22 3	17 17
PRODUCE OF LEAF PER ACRE.						
1	14 tons farmyard manure .	4 6	8 9	8 1	9 12	6 8
5	Superphosphate . . .	1 9	5 4	4 10	9 1	4 3
4 & 6	Superphosphate and potash	1 7	5 2	3 10	7 16	3 13
NITROGEN PER CENT. IN THE DRY MATTER OF THE ROOTS.						
		per cent.	per cent.	per cent.	per cent.	per cent.
1	14 tons farmyard manure[1] .	0·83	1·24	1·31	1·74	1·24
5	Superphosphate . . .	0·58	0·96	1·00	1·55	0·88
4 & 6	Superphosphate and potash	0·58	0·95	0·84	1·27	0·82
MINERAL MATTER (ASH) PER CENT. IN THE DRY MATTER OF THE ROOTS.						
1	14 tons farmyard manure .	4·96	5·92	5·74	6·37	5·42
5	Superphosphate . . .	3·85	5·08	3·97	5·33	3·90
4 & 6	Superphosphate and potash	4·11	5·13	4·75	5·59	4·54
SUGAR PER CENT. IN THE ROOTS.						
1	14 tons farmyard manure .	11·84	10·42	10·84	9·99	10·81
5	Superphosphate . . .	13·08	10·66	11·88	9·89	12·17
4 & 6	Superphosphate and potash	12·97	11·04	12·16	10·66	12·07
SUGAR PER ACRE IN THE ROOTS.						
		lb.	lb.	lb.	lb.	lb.
1	14 tons farmyard manure .	4,309	5,508	5,413	5,630	5,976
5	Superphosphate . . .	1,731	4,661	3,563	3,886	4,407
4 & 6	Superphosphate and potash	1,704	4,635	4,063	5,279	4,788
INCREASE OF SUGAR PER ACRE BY NITROGENOUS CROSS-DRESSINGS.						
1	14 tons farmyard manure .	—	1,199	1,104	1,321	1,667
5	Superphosphate . . .	—	2,930	1,832	2,155	2,676
4 & 6	Superphosphate and potash	—	2,931	2,359	3,575	3,084

[1] The percentages of nitrogen given in this line relate to the crops of 1871 only.

mediate amounts of crop, had also intermediate percentages of sugar—namely, 10·42, 10·84, and 10·81. Further, the crop with the farmyard manure alone, and the highest percentage of sugar in the roots, had the smallest amount and proportion of leaf, and the smallest percentages of both nitrogen and mineral matter in the dry matter of the roots; whilst the crop yielding the highest produce of root, and the lowest percentage of sugar in the roots, had the highest proportion and amount of leaf (9 tons 12 cwt. per acre), and the highest percentages of nitrogen and of mineral matter in the roots, conditions indicating immaturity. To these points we shall recur again presently.

The results next recorded in the Table show the amounts of produce, roots and leaves, obtained with artificial mineral manures, both when used alone and with the nitrogenous cross-dressings as before described. The Table further shows, the percentages of nitrogen and of mineral matter (ash) in the dry matter of the roots; also the percentages, and the amounts per acre, of sugar in the roots. It will be seen that the mineral manure used on plot 5 was superphosphate alone; and on plots 4 and 6 superphosphate with potash in addition (plot 4 having soda and magnesia also). The average produce of roots with either of these mineral manures used alone, was 5 tons 18 cwt. per acre; which was increased to 19 tons 11 cwt. and to 18 tons 17 cwt. by nitrate of soda =86 lb. nitrogen; to 13 tons 9 cwt. and to 14 tons 19 cwt. by salts of ammonia=86 lb. nitrogen; to 16 tons 5 cwt. and to 17 tons 17 cwt. by rape-cake=98 lb. nitrogen; and to 17 tons 15 cwt. and 22 tons 3 cwt. by salts of ammonia and rape-cake, together containing the excessive amount of 184 lb. of nitrogen. The figures further show that there was a greater produce of root, though not of leaf, in the case of three out of the four cross-dressings where potash was used as well as superphosphate; and that there was not more with than without potash where nitrate was used, is most probably explained by the fact that the nitrate distributes rapidly in the soil, encouraging a greater distribution of the roots, by which the plants acquire a greater command of the potash of the soil and subsoil. The result with the potash is fully established in other experiments; namely, that a liberal supply of it tends to root-formation and maturation, conditions favourable for the production of sugar.

The percentage of sugar in the roots is, with one exception, considerably higher where the mineral manures were used than where farmyard manure was employed, whether alone or with the cross-dressings. With the mineral manures used alone,

and less than 6 tons of roots produced, there was in one case rather over, and in the other very nearly, 13 per cent. of sugar in the roots; and in several other cases there was nearly, or over, 12 per cent. As in the case when farmyard manure was used, so now with the mineral manures, the lowest percentage of sugar in the roots was where the very excessive cross-dressing of 184 lb. of nitrogen was employed; and the amount and proportion of leaf to root at the time of taking up the crop was very large, showing that the produce was immature. In order of lowness of sugar per cent. in the roots of the other crops, came those with the cross-dressing of nitrate of soda, yielding large amounts of leaf; whilst the roots grown with the cross-dressings of salts of ammonia, or of rape-cake, showed, with somewhat smaller crops of both root and leaf, the highest percentages of sugar. It is perfectly consistent with these results as to the percentage of sugar in the roots, that in the case of plots 4 and 6, the percentages of nitrogen and of mineral matter in the roots were the lowest with the mineral manure alone and the highest percentage of sugar, and the highest with the excessive nitrogenous cross-dressing and the lowest per cent. of sugar. Next in order both as to highness of per cent. of both nitrogen and mineral matter, and lowness of per cent. of sugar, came the roots receiving the nitrate as a cross-dressing; and the roots with the cross-dressing of ammonia or of rape-cake, especially where potash was supplied, gave the lowest percentages of nitrogen and of mineral matter, and the highest percentages of sugar, among the crops with nitrogenous cross-dressings. Lastly, it is to be observed that with the nitrate, the salts of ammonia, and the salts of ammonia and rape-cake together, the percentage of sugar was distinctly higher with than without the potash; whilst where rape-cake alone was used as a cross-dressing (the rape-cake containing potash) the percentage of sugar is nearly the same without and with potash supplied.

It is quite evident from these results, that the amount of crop grown depended very largely upon the amount of nitrogen available within the soil; but that with crops forced beyond a certain moderate limit of produce, the proportion of leaf was unduly large, the percentages of nitrogen and of mineral matter in the root relatively high, and the percentage of sugar objectionably low; all these conditions indicating too much luxuriance and defective maturity at the time of taking up the crop.

The Table (p. 7) further shows, however, that the amount of sugar *per acre* also much depended on the nitrogen available within the soil. Thus, it is seen that when farmyard manure was the standard manure, notwithstanding a much lower percentage of

sugar in the roots with nitrogenous cross-dressings in addition, there was from a fourth to a third more sugar *per acre* with the cross-dressings than without; and when mineral manures were used as the standard manures, there was in every case more than twice, and in some nearly or quite three times, as much sugar per acre with as without the nitrogenous cross-dressings.

The bottom division of the table shows the actual increase of sugar produced over that obtained without nitrogenous cross-dressing, by each of the four cross-dressings, under each of the three conditions as to standard manure. This increase of sugar produced was very much less for a given amount of nitrogen supplied in the cross-dressings when they were used with the farmyard manure than with either of the mineral manures. With the nitrate the increased production of sugar was practically identical without and with potash in the standard manure; a result, as already referred to, most probably due to the great solubility and rapid distribution of the nitrate in the soil, leading to a greater root-development in the lower layers, thus giving the plants a greater command of the available potash of the subsoil, and so far rendering them less dependent on the more superficial supplies by manure. With each of the other three cross-dressings there was, however, a very marked increased production of sugar with potash supply compared with that without it.

So much for the average results obtained over three years, in our experiments on sugar-beet so long ago as 1871, 1872, and 1873. There were crops of less than 6 tons per acre, and of more than 25 tons. The percentage of sugar in the roots ranged from over 13 to under 10 per cent., according to the manuring, and the sugar per acre in the roots ranged from 1,704 to 5,976 lb., also according to the manuring.

We have for brevity thus given only the average results for three years, instead of those for each year separately. It may be stated, however, that notwithstanding the accumulation within the soil from year to year by the return of the leaves to the land, there was, with the higher manures, a tendency to reduction in produce of roots per acre from the first to the third year; and coincidently a tendency to higher percentages of sugar in the roots, especially comparing the second and third with the first season. This result is more probably due to the climatic characters of the respective seasons, than to the condition of the land; but it would occupy too much space to attempt to connect the differences of yield and composition with the differences of temperature and rainfall in the three seasons.

With the foregoing results before us, it will be of interest to

compare or contrast them with those obtained in some of the countries where sugar-beet is largely grown, and sugar is largely manufactured from it.

The Beetroot Sugar Industry in some Countries on the Continent of Europe.

When travelling to inspect some of the sugar-growing districts of Germany, Austria, France, Belgium and Holland, in 1871 and in 1872, it was found that in Germany, where the duty was paid upon the weight of roots submitted to manufacture, great attention was paid to get roots of high percentage of sugar and low percentages of "*non-sugar*," especially of nitrogenous and saline matters, which reduced the amount of crystallisable sugar obtained in the manufacture. It is strictly in accordance with the results of our own experiments which have been given, that roots of the desired character could only be produced by restricting the manuring, and by other methods of preventing over luxuriance, and favouring perfect ripening or maturity; in fact, by growing comparatively small roots and small crops per acre. Accordingly, strict rules were issued by the manufacturers to the growers, for the manuring, and for other conditions of growth. One of these was, that if farmyard manure were employed, some other crop, of feeding roots for example, should be taken before a crop was grown for sugar. Then the use of nitrate of soda was practically prohibited, though a small dressing of sulphate of ammonia might be used. The roots were to be grown at a limited distance between the rows, and between the plants in the rows. In no case was it found that the rows were more than 18 inches apart, and in some cases the distance from plant to plant in the rows was as little as 8 to 9 inches, and seldom more than 10 or 12. In this way, by limitation of the amount of nitrogenous manure, and growing the plants close together, over luxuriance was avoided, and ripe roots, with a high percentage of sugar and low amounts of nitrogenous and saline matters, were obtained. The average amount of roots submitted to manufacture, and chargeable with duty, was little more than 11 tons per acre.

In France, on the other hand, where the duty was then paid, not upon the roots, but on the manufactured sugar, and where the manufacturer was in a greater degree dependent on his neighbours for his roots than was the case in Germany, a very opposite system had grown up. In the North of France at that time, the produce of roots per acre was about double that of

Germany. As a rule, most of the manure available was applied directly to the beet crops; the other crops of the rotation being grown almost without direct manure. The result was, that the French roots were much larger and coarser, contained lower percentages of sugar, and higher percentages of nitrogenous and saline matters, than the German. Under these circumstances, a considerably larger quantity of roots had to be submitted to manufacture to obtain a given quantity of marketable sugar, and a less proportion of the existing sugar was obtained in that form. Nevertheless, the French system undoubtedly yielded more sugar from a given area of land, though at considerably more cost for manufacture.

Since July 1884, there has, however, been a great change in the French system. From that date the duty has been paid upon the roots instead of upon the sugar, and this has led to the necessity of producing roots as rich in sugar as possible, and to the payment for the roots by the manufacturer according to their richness in sugar; the price being fixed according to the density of the juice. It has thus become the interest of the cultivator to grow much smaller crops, with much higher percentages of sugar than formerly. Much more attention has also been paid to the character of the seed sown, so as to obtain roots rich in sugar.

Before referring to more recent statistics, it may be stated that, according to records quoted at p. 70 (2nd edition) of Mr. Sigmund Stein's pamphlet, it would appear that during the last twenty-five years the number of sugar factories in Germany has increased from about 300 to about 400, or by one-third. The quantity of beetroot worked has, however, increased about five-fold; the quantity of sugar produced from seven to eight fold; and the yield of raw sugar per cent. on the roots from about 8¼ to 13¼.

The following Table (II., p. 13) gives a summary of results quoted by Mr. Sigmund Stein at pp. 69–71 of his pamphlet; the results themselves being taken from the official statistics relating respectively to Germany and to France.

Referring to the figures in the upper division of the Table, relating to Germany, it is seen that during the eleven years 1886–7 to 1896–7, the number of sugar factories has remained comparatively stationary. On the other hand, the area under sugar-beet has increased by about one-half, the amount of roots submitted to manufacture by more than one-half, and the amount of raw sugar produced in a much greater proportion still. Naturally, there is fluctuation in the produce of roots per acre from year to year according to season; the

lowest amount recorded during the eleven years being 10·7 tons in 1887; the highest 13·3 tons in 1889 and in 1894; and the average of the eleven years amounts to 12·1 tons. Lastly, the amount of raw sugar produced per cent. on the roots varied during the same eleven years from 11·87 in 1886–7, to 13·11 in 1895–6, with an average over those eleven years of 12·33 per cent. But, it will be seen, it is stated that in 1884–5 the raw sugar obtained per cent. on the roots was only 10·79, and in 1885–6 only 10·43; the figures showing a marked increase subsequently to those years.

TABLE II.

Years	Number of sugar factories	Area under sugar-beet	Produce of roots per acre	Roots submitted to manufacture	Raw sugar produced	Raw sugar per cent. on the roots
			GERMANY.			
	no.	acres	tons	tons	tons	per cent.
1884–5	376	—	—	10,402,688	1,123,030	10·79
1885–6	408	—	—	7,070,317	808,105	10·43
1886–7	399	684,193	12·1	8,306,671	1,018,281	11·87
1887–8	401	651,815	10·7	6,963,960	958,863	13·08
1888–9	391	691,897	11·4	7,896,183	990,890	11·96
1889–90	396	752,259	13·3	9,822,635	1,261,353	12·36
1890–1	401	824,825	13·0	10,623,319	1,336,221	12·09
1891–2	405	861,583	11·4	9,488,002	1,198,025	12·06
1892–3	403	869,829	11·3	9,811,939	1,230,834	11·94
1893–4	401	954,995	11·1	10,644,351	1,366,001	12·34
1894–5	405	1,090,801	13·3	14,521,029	1,827,973	12·15
1895–6	397	930,749	12·5	11,672,816	1,637,057	13·11
1896–7	399	1,049,881	13·0	13,721,601	1,821,223	12·66
Mean	—	—	(12·1)	—	—	12·06
			FRANCE.			
1884–5	449	359,864	12·7	4,556,796	303,291	6·66
1885–6	413	283,987	11·9	3,385,439	294,538	8·70
1886–7	391	379,331	12·9	4,897,079	482,270	9·85
1887–8	375	397,512	9·1	3,614,632	383,049	10·60
1888–9	380	425,373	9·9	4,222,967	458,359	10·85
1889–90	373	472,821	13·0	6,676,051	777,073	11·64
1890–1	377	547,808	11·8	6,499,906	683,602	10·52
1891–2	368	551,955	10·2	5,628,804	642,023	11·41
1892–3	368	528,156	10·3	5,472,891	581,517	10·63
1893–4	370	543,645	9·6	5,250,192	571,987	10·89
1894–5	367	596,806	12·0	7,137,736	782,726	10·97
1895–6	356	505,858	10·7	5,411,484	659,607	12·19
1896–7	358	608,370	11·1	6,705,000	742,829	11·08
Mean	—	—	11·2	—	—	10·46

To form an estimate of the amount of pure sugar yielded

per 100 of roots, it is obvious that deduction would have to be made according to the degree of purity of the raw sugar, but to the amount so reduced there would have to be added the sugar obtained from, or remaining in, the molasses.

Turning now to the results relating to France, as given in the lower division of the Table, it is seen that there has been a gradual reduction in the number of sugar-factories during the thirteen years commencing with 1884–5, and ending with 1896–7; that is, since the new system as to the valuation of the roots, and the resulting changes in the cultivation and manufacture, have been adopted. Notwithstanding the reduction in the number of factories, there has been a gradual increase in the number of acres under the crop by about one-half, comparing the first five with the last five of the thirteen years. With the great improvement in the quality of the roots under the new system, the produce of roots per acre was, on the average of the thirteen years, only 11·2 tons, or rather less than the yield in Germany, and only about half as much as in France about twenty-five years ago. Nevertheless, the amount of roots submitted to manufacture has increased by about one-half, comparing the quantities over the last five years with those of the first five of the thirteen under the new system; whilst, reckoned in the same way, the raw sugar produced has increased by more than one half. Lastly, the amount of raw sugar obtained from 100 of roots has, under the new system, increased during the later compared with the earlier years; but the average amount over the thirteen years 1884–5 to 1896–7, for which there are corresponding particulars for Germany, show only 10·46 of raw sugar obtained from 100 of roots, against 12·06 over the same period in Germany. In any reckoning of the total amount of pure sugar yielded per 100 of roots in France, the amount obtained from, or remaining in, the molasses, would of course have to be added to that contained in the raw sugar; but the total yield, in raw sugar and molasses, would still be materially less than in Germany.

From the foregoing results relating to the sugar industry in Germany and France in recent years, it is obvious that, to get a high yield of sugar from the roots, only comparatively low yields of roots per acre can be obtained.

It has before been stated, that twenty-five years ago under the restrictions then in force as to the manuring and the cultivation of the sugar-beet crop in Germany, the average produce was not more than about 11 tons of roots per acre; but, as the Table shows, the average yield over the eleven years to 1896–7 was over 12 tons. The increase in produce per acre in recent

years is partly due to some changes in the manuring and cultivation of the crop. Formerly, as has been said, sulphate of ammonia was used in limited amount per acre; but nitrate of soda very seldom, owing to the reduced coefficient of purity of the juice when it was employed. More recently, however, nitrate of soda has been more and more used, almost to the exclusion of sulphate of ammonia; the difficulty as to the less purity of the juice of the beets being to a great extent obviated by growing the plants closer together, so as to prevent over-luxuriance and ensure the ripening of the roots. To maintain and to increase the percentage of sugar in the roots, great attention has also always been paid in Germany to the character of the seed sown; high character being attained by selection of the roots to be grown for seed; and in recent years higher and higher percentages have been obtained, so that, with even somewhat increased weight of roots per acre, the percentage of sugar in the roots has been increased, and that of the "non-sugar" diminished. The result is an almost perfect root for the purposes of manufacture.

It is obvious from the results in the Table (II., p. 13) that since the new system of purchasing the roots according to their richness in sugar has been adopted in France, the character of the roots for the purposes of sugar-making has been much improved, and their produce of manufactured sugar has been greatly increased. But hitherto, though with even smaller crops, as has been shown, a less yield of sugar per cent. on the roots is obtained than in Germany.

Value of Sugar-beet Roots according to their Composition.

The price which the manufacturer will pay for roots depends upon two factors:—First, the percentage of sugar in the roots; and, secondly, what is called the "coefficient of purity" of the juice. It is said that some German factories refuse roots containing less than 10 per cent. of sugar. But, whatever the percentage of sugar in the roots, the price given per ton depends largely on the purity of the juice. The degree of purity of the juice means the percentage in the dry matter of the juice of sugar as indicated by the polariscope. In other words, it means the percentage of sugar in the total dry substance of the juice.

For example, if the percentage of dry matter in the juice were found to be 16, and the percentage of sugar in the juice by polariscope were 12, it is obvious that the sugar would represent three-quarters of the dry substance; in other words, 75 per cent. If, on the other hand, the percentage of dry

matter in the juice were still 16, and that of the sugar 13, the percentage of sugar in the dry matter, that is the coefficient of purity of the juice, would be 81·25. Or, to give another example, if the percentage of dry matter in the juice were 17, and that of the sugar were 15, the co-efficient of purity of the juice would be 88·24. It may be said that a juice of a purity of 80 per cent. or more would be considered a good juice, and the price of the roots would accordingly be high; but roots with a juice of only 75 or lower per cent. purity, would command a lower price from the manufacturer, even although the percentage of sugar in them was the same in the two cases. An example of this may be given from the scale adopted at a sugar factory in the United States, which will be referred to in more detail further on. Thus, roots containing 12 per cent. of sugar, with a juice of 80 per cent. purity, were paid for at the rate of 4 dollars (=16*s.* 8*d.*) per ton; whilst roots still containing 12 per cent. of sugar, but with a juice of only 74 per cent. purity, were paid for at the rate of only 3 dollars (=12*s.* 6*d.*) per ton.

We are not aware of authentic records showing either the actual average percentage of sugar in the roots, or the actual scale of prices paid by the manufacturer for the roots according to their percentage of sugar, and the purity of the juice, in recent years in Germany; but we believe that when the percentage of sugar in the juice is above a certain amount, the question of the purity of the juice is disregarded.

The following Table (III., p. 17) is, however, founded on data given by Dr. Carl Stammer, one of the chief beetroot sugar experts in Germany, which were published some years ago. He gave results for thirteen different percentages of sugar in the roots, from 10, 10·5, 11·0, 11·5, and so on, up to 16·0, and for each of these percentages at six different degrees of purity of the juice. He then adopted the percentage of 12 sugar in the roots, with a purity of the juice of 80, and assumed this quality of root as unity, and valued it at 2 francs per 100 kilograms (=220½ lb.). Adopting his data, we have given in the Table, in English money, the value per ton of roots of the different percentages of sugar as shown at the head of the columns, each at the six different degrees of purity of juice.

Of course the actual standard price of roots of a fixed quality will vary considerably from time to time, according to the price of sugar in the market, and to the productiveness of the season, and other local circumstances. But the lesson to be learnt from the Table is, how great may be the difference in the value of the roots according to their composition; that is, according to their percentage of sugar, and to the degree of

purity of the juice. Roots of only 10 per cent. of sugar would most probably also have a low degree of purity of juice; and adopting the standard price upon which the Table is based, the value of the roots per ton would probably be only about 11*s.* or 12*s.* If the percentage of sugar in the roots were 11·0, the purity of the juice would probably be somewhat higher, but still low, and the price might range from 13*s.* to 15*s.* per ton. If the percentage of sugar were 12·0, a higher condition of juice might be expected, and the price might be from 16*s.* to 17*s.* per ton. With a percentage of sugar of 13·0, there would again probably be a higher purity of juice, and the price per ton of roots might, on the scale supposed, be from 17*s.* 6*d.* to about 20*s.* With 14·0, 15·0 or 16·0 per cent. of sugar in the roots, the purity of the juice would pretty certainly be high, and the value of the roots per ton might range from 20*s.* to 25*s.*

TABLE III.

Quotient of purity	Sugar in the Roots											
	10·0 per cent.		11·0 per cent.		12·0 per cent.		13·0 per cent.		14·0 per cent.		15·0 per cent.		16·0 per cent.	
	s.	*d.*	*s.*	*d.*	*s.*	*d.*	*s.*	*d.*	*s.*	*d.*	*s.*	*d.*	*s.*	*d.*
70	11	11	13	0	14	2	15	5	16	7	17	9	19	0
75	12	8	13	10	15	3	16	5	17	9	19	0	20	4
80	13	6	15	0	16	3	17	7	19	0	20	4	21	8
85	14	6	15	9	17	3	18	6	20	2	21	6	23	1
90	15	3	16	9	18	3	19	10	21	4	22	11	24	5
95	16	1	17	7	19	4	20	10	22	7	24	1	25	8

Obviously, if the standard price of the period or locality were lower than that adopted in the construction of the Table, the price per ton for any given quality of roots would be lower; or if the standard price were higher, so would the price per ton of roots be higher for any given composition than that given in the Table.

It has been explained that the system in France before 1884 was for the manufacturer to purchase the roots by weight irrespectively of their composition, and the result was that large crops of low percentage of sugar, and doubtless low purity of juice, were produced. In 1884, however, the system being changed, and the roots from that time being paid for according to their composition, much smaller quantities of roots per acre, but with much higher percentages of sugar and higher quality of juice, have been grown, and accordingly much higher prices have been paid for the roots.

It will be useful to give an illustration of the condition of things in France prior to 1884, by giving a summary of a Table

published in 1876 by M. Georges, President du Comice Agricole of Saint-Quentin, at a time when the importance of payment according to composition had been recognised and discussed, though not definitely established, and when, as a first step, it was proposed to value the roots according to the density of the juice. M. Georges gave a Table for 31 different degrees of density, corresponding to from 13·3 to 6·7 per cent. of sugar in the roots; giving, at the same time, the yield obtained per 100 of roots of the different qualities, and the price per 1,000 kilos. (2,204½ lb.) accordingly. The following Table (IV.) is constructed according to the data given by M. Georges, and shows the value per ton of roots in English money for each percentage of sugar in the roots from 13 down to 7.

TABLE IV.

Sugar in the roots	Yield of sugar in the roots	Proportion of the total sugar yielded	Price per ton of roots
per cent.	per cent.	per cent.	*s.* *d.*
13	8·53	65·6	19 3
12	7·82	65·1	17 7
11	6·99	63·5	15 9
10	6·22	62·2	14 1
9	5·38	59·7	12 2
8	4·61	57·6	10 5
7	3·88	55·5	8 9

The first point to observe in the Table is, the small proportion of the total sugar in the roots that is obtained in the manufacture; the amount being only 65·6 per cent., with 13 per cent. of sugar in the roots, and as little as 55·5 per cent. with only 7 per cent. in the roots. Accordingly the estimated price per ton of the roots was 19*s.* 3*d.* with the highest percentage; gradually declining with each lower percentage of sugar, and lower proportion of the total sugar yielded, to only 8*s.* 9*d.* per ton with only 7 per cent. sugar in the roots, and the much lower proportion of the total sugar obtained in the manufacture; due, doubtless, to the much lower degree of purity of the juice. The much lower value to the manufacturer of roots not only lower in percentage of sugar, but with this having a proportionally lower degree of purity of the juice, and giving a lower yield from a given percentage, is here again clearly illustrated. The low yields of sugar obtained from the roots on the old system in France is also prominently brought to view.

The following illustrations of the comparatively large produce of roots per acre, of high percentages of sugar in the roots, and of high prices obtained per ton for them, in some special

instances, since the new law has been in force in France, and the roots have been paid for by the manufacturer according to their percentage of sugar as determined by the amount in the expressed juice, are of interest, and are in striking contrast to those given in Table IV. (p. 18). The results are given by Professor P. P. Dehérain, in a paper published in 1887—and in the following Table (V.) the quantities he gives are converted into English weights and money. The roots were grown at Wardrecques, Pas-de-Calais, and it is stated that the first four were obtained on small experimental areas, but the others in large culture. It is further stated that the conditions were in every respect arranged with the special object of obtaining roots of the highest possible quality and value.

TABLE V.

Description of seed, &c.	Per cent. sugar in the roots	Roots per acre	Sold at per ton
	per cent.	tons cwt.	*s.* *d.*
Vilmorin, 1885	16·3	17 11	31 9
„ 1886	—	15 19	31 11
Dippe, 1885	15·8	18 8	30 1
„ 1886	—	18 11	27 8
Vilmorin and Dippe . .	14·7	19 1	25 10
	15·1	18 11	27 5
	16·4	16 8	36 9
	18·5	14 3	50 2
Vilmorin	—	—	42 11
Dippe	—	—	34 4

It will be seen that in the cases in which the percentage of sugar in the roots is given, it was very high; and not only in a very marked degree higher than in the range assumed in Table IV. (p. 18), relating to the period before the establishment in France of the rule of payment for the roots according to their richness in sugar, but also in some cases higher than the highest assumed in Table III. (p. 17), arranged specially for use in Germany. The weights of roots per acre, though very much lower than the earlier average for France, are nevertheless very high for such rich roots, and much higher than the average in Germany; and the percentages of sugar are also considerably higher than the average in Germany with only from 12 to 13 tons of roots per acre.

It is true that the above results were in a certain degree only experimentally obtained; but they are nevertheles interesting and instructive, as showing what may be done when sufficiently careful attention is paid to the essential conditions

of growth to obtain a good result. The prices given per ton of roots, which are stated to have been actually paid for them, show that they ranged from a minimum of 25*s.* 10*d.* with 14·7 per cent. of sugar, to 50*s.* 2*d.* with 18·5 per cent. of sugar! The prices were, in fact, in most cases one and a half time, and in some twice, as high as was proposed for roots of 13 per cent. sugar, as in Table IV. (p. 18), relating to the condition of things before the change of 1884. It is at any rate quite certain that such high percentages of sugar, with such large crops, could only be attained under exceptionally favourable conditions as to description of seed, character of soil, of manuring, of climate, and of cultivation. So far as can be judged from the particulars given, the manuring consisted, at any rate in some cases, of maize-cake, and in others of sulphate of ammonia, each with superphosphate in addition. Further, the most approved seed was used, and the plants were grown very close together, there being between eight and nine per square yard.

It may, of course, be a question, how far examples taken from countries like Germany and France, where the manufacturer of sugar is subject to the payment of heavy duties, and where, on the other hand, heavy bounties are given on the export of sugar, are any safe guide as to the probable range of prices that would prevail in our own country, if the growth of sugar-beet for sugar, and the manufacture of sugar from it, were established here under totally different fiscal conditions.

After the foregoing had been sent to the printer, we received an interesting communication on the conditions of sugar-beet cultivation in France at the present time, which has been very kindly prepared for us, in answer to questions we had submitted to him, by Monsieur E. Tisserand, formerly Director of the Ministry of Agriculture, Paris, but recently retired, and now Honorary Director.

The following is a translation of the document, with the quantities converted into their equivalents in English weights, measures, and values :—

1. Since the coming into force of the Law of 1884, which imposed the tax upon the beetroots submitted to manufacture, certain changes in the methods of cultivation have become necessary. The rotation remains, however, triennial as before : beetroot manured, wheat, and oats. It is essential that the organic manures—farmyard manure, compost, poudrettes, &c., should be put on the land as soon as the preceding crop is removed, and that their thorough mixing with it should be completed by the end of September, so that

they may have plenty of time to decompose and become well incorporated with the soil. Without this, they act too slowly on the vegetation, and so prevent the maturation of the roots at the time required. The quantity of farmyard manure applied is from 14 to 16 tons per acre; and this is supplemented in the spring by the application of from 3 to 5 cwt. per acre of bone or mineral superphosphate, and of from 2¼ to 3¼ cwt. of nitrate of soda. If the soil requires potash, this may be advantageously supplied by from 1¼ to 1¾ cwt. of chloride of potassium. The seed is sown in rows about 16 inches apart, so as to admit of the use of a horse-hoe, which is desirable for maintaining the proper condition of the soil. When the plants have developed four leaves, they should be thinned out, leaving one every 10 or 12 inches, so as to secure seven or eight per square yard, and by this close growth to prevent the individual plants attaining too great development, which is always injurious to the quality.

2. The beetroots are bought according to the density of the juice. The price is fixed for beetroots showing 7°, corresponding to 14 per cent. of sugar, according to the current price of sugar; the deviation ranging from 3*s.* 3*d.* to 5*s.* 6*d.*, according to the locality, and to the competition that there frequently is between the buyers. Example: If sugar is worth 12*s.* per cwt. during the months of manufacture, the standard price for roots should be 18*s.* to 22*s.* per ton at 7° density; with an increase or reduction of 6*d.* to 7*d.* for every tenth of a degree above or below 7°. Generally beetroots with a density below 6·5 are not received.

3. The quality of the roots is very variable, and depends much on the conditions of the weather during the growth of the crop. The months of September and October have very great influence in this respect. But it is of all things very important that the vegetation should be continuous, and not suffer any check during the hot weather of July and August.

4. Beetroots in France have an average of from 13 to 15 per cent. of sugar, and there is extracted in the manufacture from 9½ to 12 per cent., according to the richness of the roots, and materially also according to the methods of working of the manufacturer.

5. In the estimates of the amounts of sugar extracted, sugar of at least 99 per cent. purity is to be understood.

6. Statistics show that in France the general average of the beetroot crop is 11 tons 3 cwt. per acre, and in Germany 12 tons 7 cwt. But, on a well managed farm, 14 to 16 tons of roots per acre, containing from 14 to 15 per cent. of sugar, are not seldom obtained.

7. The average price paid for roots during recent years has ranged from 19*s.* 6*d.* to over 21*s.* per ton, with a density of 7°.

8. The capital-value of the land is from 48*l.* to 64*l.* per acre, according to district, quality, situation, &c. According to the same conditions, the rental varies from 22*s.* 6*d.* to 42*s.* and 45*s.* per acre. For some years the price of white sugar No. 3 has been about 12*l.* 4*s.* per ton delivered in Paris; but varying between the extremes of 10*l.* 3*s.* and 13*l.* 8*s.*

Growth of Sugar-beet, and the Manufacture of Sugar from it, in the United States.

An illustration from the experience so far gained after a few years' trial in the United States, will be of interest. In January of the present year, Professor Woll, of the University of Wisconsin, at Madison, published a report on "Sugar-beet Investigations in Wisconsin in 1897," giving, besides others, the results of more than two thousand experiments on the growth of sugar-beet in that year, and of the analyses of the samples.

In reference to the question of the *Relative Value of Beets of Different Purities*, Professor Woll states that some factories do not receive beets showing less than 80 per cent. purity, whilst others receive them at a reduced scale of prices; and he quotes, as in the following Table (VI., p. 23), the schedule of prices in force at the Oxnard Beet Sugar Co.'s Factory, at Grand Island, Nebraska, according to the printed contract which the company makes with the sugar-beet growers. In the fourth column we have given the equivalent of the dollars in English money; in the fifth the values on the assumption of 20*s.*, and in the sixth on that of 25*s.* (instead of 16*s.* 8*d.*), as the price per ton for the highest quality of roots given in the Table.

It is seen that roots of 12, 13, and 14 per cent. sugar respectively, may each command the highest price, if those with 12 per cent. have a purity of not less than 80 per cent., those of 13 per cent. of not less than 78 per cent., whilst those of 14 per cent. are taken regardless of purity. Roots of 13 or 12 per cent. sugar have, however, a gradually declining value down to 3 dollars, as the degree of purity of the juice declines below 80 or 78. Further, roots with only 11 per cent. of sugar, but with a relatively high degree of purity, may have the same value per ton as those with 12 or 13 per cent. but with a lower degree of purity. Lastly, as the bottom lines of the Table show, roots with less than 13 per cent., less than 12, or less than 11 per cent., and with low degrees of purity, would be worth only 2½ dollars

per ton. Thus, roots may contain from 12 to 13 per cent. of sugar, and yet their value per ton may vary from 4 dollars (16*s.* 8*d.*) to 2·50 dollars (10*s.* 5*d.*), according to the degree of purity of the juice.

TABLE VI.

Beets containing not less sugar than—	Degree of purity of the juice	Prices per ton of roots					
		American scale			Assuming		
		dollars	*s.*	*d.*	*s.*	*d.*	*s.*	*d.*
12 per cent.	80 per cent.	4·00	16	8	20	0	25	0
14 ,,	Regardless of purity	4·00	16	8	20	0	25	0
13 ,,	Not lower than 78 p.c.	4·00	16	8	20	0	25	0
13 ,,	,, 76 ,,	3·75	15	7	18	9	23	5
12 ,,	,, 79 ,,							
13 ,,	,, 75 ,,	3·50	14	7	17	6	21	10
12 ,,	,, 78 ,,							
13 ,,	,, 74 ,,	3·25	13	6	16	3	20	4
12 ,,	,, 76 ,,							
11 ,,	,, 78 ,,							
13 ,,	,, 73 ,,	3·00	12	6	15	0	18	9
12 ,,	,, 74 ,,							
11 ,,	,, 75 ,,							
Below 13 p.c.	,, 73 ,,	2·50	10	5	12	6	15	7
,, 12 ,,	,, 74 ,,							
,, 11 ,,	,, 75 ,,							

The Table does not assume what would at the present time be considered high percentages of sugar in either Germany or France; and, especially with the lower percentages, the degrees of purity are also low. The figures, nevertheless, illustrate very clearly the importance to the grower as well as to the manufacturer of high quality of roots. For example, let us assume that a crop of 15 tons per acre grown from high quality of seed, with the land in good condition, appropriately manured, and not less than nine plants to the square yard, might, in a favourable season, contain not less than 13 per cent. of sugar, with a degree of purity of 78. It would then command, according to the American schedule, 16*s.* 8*d.* per ton; or let us assume 20*s.* per ton. If the crop reached 20 tons, the probability is that the percentage would not be more than 12, and the degree of purity not higher than 74, and the price would then be only 15*s.* a ton. Or, if the crop reached 25 tons, the percentage of sugar would probably not exceed 11, and the degree of purity would be low;

in which case the price would be only 12*s.* 6*d.* per ton. On these assumptions the value of the crops per acre would be as follows:—

	£	*s.*	*d.*
15 tons at 20*s.* per ton	15	0	0
20 tons at 15*s.* per ton	15	0	0
25 tons at 12*s.* 6*d.* per ton	15	12	6

This is only one illustration, on certain fixed assumptions, which by no means exaggerate the probable differences in composition and value of such crops. Indeed, the probability is that, in actual practice, the differences in favour of growing comparatively small crops, with high percentage of sugar and high purity of juice, the result of perfect maturation, would frequently be much greater than the figures above given suppose. Then, it is unlikely that crops of 15 tons per acre could, in the average of seasons, be grown of such quality as is above assumed; whilst crops ranging from 12 to 15 tons, if grown from suitable seed, and under suitable conditions as to soil, manuring, and cultivation, would probably yield roots of higher quality, commanding higher rates of value than those above supposed.

General Conclusions.

One of the first questions to consider in forming a judgment as to whether success would attend an extended growth of sugar-beet, and the establishment of factories for the manufacture of sugar, in this country is—at what price of sugar is it probable that such an enterprise would be profitable? Mr. Sigmund Stein estimates that 400 factories, each costing about 50,000*l.*, would supply all the sugar required for consumption in the United Kingdom. Going into more detail he says: "A sugar factory working 40,000 tons of roots, the crop of say 3,000 acres, would produce about 5,000 (5,200) tons of sugar, and would cost to erect about 60,000*l.*" Giving a summary balance sheet, he reckons that there would be a profit of over 6 per cent. on the 60,000*l.* capital, if the price of sugar were 9*l.* per ton, of 14¾ per cent. if 10*l.*, of 23·4 per cent. if 11*l.*, and of 32 per cent. if 12*l.* per ton.

Besides the great pecuniary advantages thus assumed on the expenditure of capital in the erection and working of sugar factories, there has, of course, to be taken into account the benefits that would accrue to agriculture, in the profitable employment of so much land, and also of so much labour, both in the field and in the factory. In Mr. Stein's estimate of the pecuniary benefits to the farmer, he takes the cost per acre of

growing sugar-beet at 10*l.*, and assumes that he will receive 18*s.* a ton for fifteen tons of roots delivered to the factory. If the farmer were to be paid for 15 tons of roots, this must mean 15 tons after cleaning and trimming, which implies considerably more than fifteen tons of gross produce of roots per acre. Then Mr. Stein reckons that the roots would produce 13·3 per cent. of sugar, and says that its cost price would be 9*l.* per ton. We assume that raw sugar, not refined, is meant; but it is important to know the percentage of pure sugar in the product. If refined sugar were meant, there would have to be more than that percentage in the roots grown; and although in favourable localities and seasons it would probably be obtained, it is not likely that it would be in roots of 15 tons per acre or more, taking the average of seasons. In fact, if the land were to produce 15 tons or more per acre of roots, containing say between 13 and 14 per cent. of sugar, the cost per acre of manuring and cultivation, with other expenses, would be more than 10*l.*, and the farmer would not be satisfied with 18*s.* per ton for trimmed roots. Still less would he be so if the desired richness in sugar could only be attained with smaller crops per acre.

It may here be observed that it is difficult to follow some of Mr. Stein's calculations. For example, in reckoning the profit to the farmer on growing 15 tons of roots per acre, he credits him with 1*l.* 5*s.* for the value of 5 tons of leaves and heads from the roots, thus mixing them up together, and rendering it impossible to form an estimate of the probable loss of weight of roots by trimming. He also reckons 3 tons of slices (pulp) equal 20 per cent. of the quantity of roots delivered, valuing them at 10*s.* per ton to the farmer [1]; but in estimating the profits of the factory he reckons the slices at 30 per cent. of the weight of roots, but still values them at 10*s.* per ton. In fact, although Mr. Stein's pamphlet supplies a great deal of valuable information, the details do not afford a sufficient basis to justify the opinion that the farmer would make the profit supposed, or that the factory would earn 6 per cent. on the capital with a price of 9*l.* per ton of sugar, or as much as is assumed with the respective prices of 10*l.*, 11*l.*, or 12*l.* per ton of sugar.

With regard to the suitability of the climate of the British Isles for the growth of beetroot in sufficient quantity, and at the same time of adequate richness in sugar, Mr. Stein says that it has been proved by hundreds of experiments during the last

[1] In his first edition he reckoned 6 tons of slices, equal 40 per cent. of the quantity of roots delivered, valuing them at 5*s.* per ton to the farmer.

fifty years—"that the sugar contained in the home-grown beet-root is not only equal to, but even surpasses, that contained in the beetroot grown on the Continent of Europe." We certainly are not aware of the results referred to, and although we do not doubt that crops of adequate quantity and quality could be grown in suitable localities, and in some seasons, we do not believe that they could be over the country generally, or on the average of seasons. Then, Mr. D. T. Fish, writing in the *Agricultural Gazette* asks: "Who needs experimental plots to prove the practicability of good profitable crops of sugar-beet in our soil and climate? Assuredly not those farmers to be found in thousands on both sides of the Tweed who can grow mangels, swedes, or turnips to almost any weight from 20 to 40 tons per acre?" So far as the experience in the growth of the different descriptions of feeding roots above enumerated, in different parts of the country, is concerned, it certainly does not point to the conclusion that the climate of Great Britain as a whole is well suited to grow sugar-beet for the economical production of sugar. It is generally recognised that feeding mangels, which are closely allied to the sugar-beet, thrive the best in the warmest parts of England; and they are very little grown in Scotland.

Those who have thoroughly studied the question of the most suitable temperature for the growth of sugar-beet, come to the conclusion that a summer *mean temperature* of not less than 70° F. is desirable to ensure success. Dr. H. W. Wiley, Chief of the Division of Chemistry of the Department of Agriculture, at Washington, says: "As a result of many years' careful experimentation, it may be said that as far as temperature alone is concerned the sugar-beet attains its greatest perfection in a zone of varying width through the centre of which passes the isothermal line of 70° F. for the months of June, July, and August." He then describes the course of this isothermal line, and says:—"Extending a distance of 100 miles on each side of this isothermal line is a belt which, for the present, may be regarded as the theoretical beet-sugar area of the United States." Indeed, the area in the United States which so far as temperature is concerned is suitable for the growth of the crop for the manufacture of sugar, points to the possibility that the United States may before very long produce all the sugar they require; and it is understood that in order to encourage the home-industry, the United States Government have it in contemplation to put a Customs duty on imported sugar equivalent to the bounties granted in the countries of export.

How far even the East and South of England are from having an average summer and autumn mean temperature of 70° F. may be judged from the figures in the following Table (VII.), showing the average *maximum*, *minimum*, and *mean temperatures*, at Greenwich, over the period of fifty years from 1841 to 1890, in each of the months of June, July, August, September, October, and November.

TABLE VII.

Temperature	June	July	August	Sept.	October	November
	°F.	°F.	°F.	°F.	°F.	°F.
Maximum . .	70·9	74·0	72·8	67·3	57·7	48·8
Minimum . .	49·9	53·1	53·0	49·1	43·3	37·6
Mean . . .	59·4	62·5	61·6	57·2	50·0	43·2

It will be seen that although the months of June, July, and August, show an average *maximum* temperature of more than 70° F., and September not 3° below it, the highest *mean* temperatures are—in July only 62·5°, in August 61·6°, in June 59·4°, and in September 57·2° F. Not a single month, therefore, approaches to an average *mean temperature* of 70° F., whilst that of September is less than 60°, and that of October only 50°. It is obvious, therefore, that so far as temperature is concerned, we should be at a disadvantage compared with other beetroot sugar producing countries. Nevertheless, it is probable that, in the majority of seasons, sugar-beet could be grown of fair quality for sugar-making in the most favourable districts of the country, which would be in the eastern and southern counties. Every farmer knows the importance of autumn growth for feeding roots; but October is often a rainy month, little suited for the ripening of a sugar crop; whilst sugar-beet would be very liable to injury from early frosts, a risk which would have to be avoided by not leaving the crop out too long, even if the growth was still active. An important means of securing early maturity is, however, the growing of the plants so close together as to limit luxuriance, and favour ripening.

Assuming that the result of all the discussion that is now taking place on the sugar-beet question were the formation of companies with sufficient capital to establish sugar factories in some of the most promising districts for the growth of the roots, it is probable that Norfolk or Suffolk would be the first selected as having the most suitable climate. The next important point would be to select soils adapted to the purpose, which should be of a medium character, neither too heavy nor too light. There are sufficient areas of such soils in the counties named;

but the difficulty would be to find enough within sufficiently easy reach of a factory. Supposing an average of 15 tons of trimmed roots per acre, of high quality, were aimed at, it would require not much less than 3,000 acres to supply 40,000 tons to the factory; though it is doubtful whether so much of high quality, commanding the highest price, would be obtained on the average of seasons. Then, as sugar-beet would not be grown every year, and perhaps not as often as once in two years, it would require about 6,000 acres, or more, according to the rotation adopted, to be devoted to the purpose, to ensure the necessary supply to the factory, and certainly not a step should be taken towards the establishment of a factory until the necessary supply of roots had been assured. It is, however, probable that for some time at any rate, the company would themselves have to grow a considerable quantity of the beets they required. Further, it is pretty certain that it would require an offer of more than 18*s*. per ton, to tempt farmers to engage to grow on the average sufficient roots of the high quality desired. For, as has been stated, if 15 tons of trimmed roots had to be supplied, more than 15 tons of gross produce would have to be grown, whilst it is doubtful if such crops would on the average be rich enough in sugar; and if less crops had to be grown to secure good quality, the return per acre to the farmer would be so much the less.

Obviously, if considerable areas of land were devoted to sugar-beet in the localities the most suitable as to climate and other circumstances for its growth, and factories were established for the manufacture of sugar from it, there would be greatly increased employment for the population; and it is a question whether the local labour of the districts would be adequate for the autumn work in the fields, and subsequently for that required in the working of the factory. In fact, there is little doubt that the wages of the locality would rise.

Reviewing the whole of the facts that have been adduced, both as to the climate and other conditions essential for the production of sugar-beet in sufficient quantity, and of sufficient quality, we are disposed to think that so far as the production of the roots is concerned, it could only be a success over comparatively limited areas, and not throughout the agricultural districts of Great Britain generally. Then, as to the profits of the sugar factories if established, the cost to the companies of roots of good quality would pretty certainly be more than has been estimated; and it is very doubtful whether, with the present price of sugar in the market, adequate profits from the manu-

facture could be expected. Supposing that the bounties granted in the chief beetroot sugar producing countries on the Continent of Europe on the export of sugar were either abolished or considerably reduced, the price of sugar would probably rise in our own country, but whether sufficiently to ensure the success of sugar-beet growing, and of sugar factories established here on a considerable scale, may be doubted.

In writing upon the subject of Allotments and Small Holdings[1] some years ago, we pointed out that by reason of our less favourable climate we suffered under disadvantages compared with some continental countries in the profitable production of certain industrial and market garden crops, and other products, which occupied the labour of small holders on the Continent. In what we have now said as to the growth of sugar-beet, and the production of sugar from it, in this country, we can, of course, have no wish to discourage an enterprise which, if successful, would not only contribute to the increased prosperity of our agriculture, but would add to our manufacturing industries. But, having been asked to write upon the subject, we felt it incumbent upon us to endeavour to supply such information as we were able, on various points, especially with regard to the essential conditions for the successful growth of a sugar-crop, at the same time not overlooking the commercial aspects of the subject. Our object has, in fact, been, as far as possible, to aid those who are disposed to consider the question to form a reasonable judgment on the probabilities of success. It is, we think, at any rate clear that, if the sugar-beet industry is to be established with any prospect of success, great caution should be exercised in the choice of the locality or localities, and that the undertakings should, in the first instance, be limited in number and confined to the most suitable localities. Should success in these accrue, the enterprise could easily be extended, for capital is never wanting in this country for any undertaking which has a fair prospect of success.

JOHN BENNET LAWES.
J. HENRY GILBERT.

Rothamsted.

[1] Journal R.A.S.E., 3rd series, vol. iii. 1892, pp. 439–463.

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THE

WORLD'S WHEAT SUPPLY

BY

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AND

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Reprint of Letter in The Times, December 2, 1898

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1898

THE WORLD'S WHEAT SUPPLY.

(Reprint of Letter in THE TIMES, December 2, 1898.)

THE President of the British Association is always selected for that distinguished position on account of his great scientific attainments. When the present President, Sir William Crookes, startled his audience at the late meeting of the Association at Bristol, by telling them that—"England and all civilised nations stand in deadly peril of not having enough to eat"—we may feel sure that not only would his hearers be startled, but that the alarm would spread over the civilised world. Having ourselves paid considerable attention to the subject of the home and foreign production of wheat, we have several times been asked to say something on the momentous question raised by Sir William Crookes. In complying with the request, we should at the outset say, that we do not propose to criticise in any detail Sir William Crookes's statistics, but only to call attention to some points, the consideration of which it is of importance to bear in mind.

No one can deny Sir William Crookes's statement that —"land is a limited quantity." But his further statement that—"as mouths multiply, food resources dwindle"—is more open to question. Sir William Crookes first considers what will be the position of this country under "the universal dearth to be expected." He seems to think that we must for the future depend more on our own resources, and less upon imports for the wheat required to feed our population. He

says—"A total area of land in the United Kingdom equal to a plot 110 miles square, of quality and climate sufficient to grow wheat to the extent of 29 bushels per acre, does not seem a hopeless demand." He further points out, that the area thus required is about one-tenth of the total area of the United Kingdom. On this point it is to be borne in mind that the total area (77,672,816 acres) includes land and water, and uncultivated as well as cultivated land; whilst, according to official statistics, there were in 1897 only 19,943,843 acres of arable land, and 27,924,710 acres of permanent grass, making together only 47,868,553 acres available for agricultural purposes out of the total area of 77,672,816 acres. Sir William Crookes, however, expresses doubt whether the amount of land supposed could be kept under wheat, except under the imperious pressure of impending starvation, or the stimulus of a national subsidy, or permanent high prices; and he assumes that all the land now under barley and oats would not be suitable for wheat, and that for the present our annual deficit must be imported.

As the question whether or not the United Kingdom could grow enough wheat for its population is one to which we have paid a good deal of attention, and on which we have published our opinion more than once, it may be well briefly to summarise it here. Taking Sir William Crookes's estimate of the amount of land required for this purpose to be about 8 million acres, the argument at the present time would be somewhat as follows :—As above stated, the total arable area of the United Kingdom was, in 1897, rather under 20 million acres, so that the above requirement for the growth of wheat would absorb about two-fifths of the existing total arable area of the country; and such a scheme would obviously soon require more. Our dependence on foreign produce would, however, not thus be lessened; for we should have to depend on imports to supply the place of the other grain crops, and the stock foods, displaced by the devotion of so much more land to wheat. Or, if the area at present devoted to these other crops were to be maintained as at present, the total arable area would have to be increased to the extent of the increase in the area under wheat, thus trenching on the land now devoted to permanent grass. It is obvious that under

such circumstances our live stock would have to be reduced, and our imports of live animals and meat very much increased. Such would be the case with our present population, to say nothing of continued increase, and of the fact that there is proportionally very little possible increase in our own food-producing area. In any case, therefore, a material increase in our own area under wheat would not reduce the imports requisite to meet the food requirements of the people, but would only substitute those of wheat for those of barley, oats, stock foods, or meat, or all of these. This is assuming that the change proposed were to be a permanent one. But if it were to be only temporary to meet the exigencies of war, or of dearth in other countries, the circumstances of the time would indicate what derangement of our agricultural system would yield the most food, and be the least objectionable.

Sir William Crookes dismisses the subject of our own home production with the remark that—"We eagerly spend millions to protect our coasts and commerce; and millions more on ships, explosives, guns, and men; but we omit to take necessary precautions to supply ourselves with the very first and supremely important munition of war—food." It is rather hard thus to be told that we are negligent upon the important subject of our food supply, when, up to the time of the Bristol meeting, the remedy had been locked up in Sir William Crookes's brain! The truth is, that we produce more per acre of every staple food suited to our soil and climate, than any other country in the world. But we have a greater population in proportion to our cultivable area than any other country in Europe; and it is simply impossible to provide the food required without very large importation. In fact, it would require very extensive emigration to bring down our population within the limits of our own possible food supply.

Sir William Crookes next reviews the capabilities of the world in the future for the production of wheat. He says:—"For the last thirty years the United States have been the dominant factor in the foreign supply of wheat. . . ." And further:—

> Almost yearly, since 1885, additions to the wheat-growing area have diminished, while the requirements of the increasing population of the States have advanced, so that the needed American supplies have been drawn from the acreage hitherto used for exportation. Practically there remains no

uncultivated prairie land in the United States suitable for wheat-growing. The virgin land has been rapidly absorbed, until at present there is no land left for wheat without reducing the area for maize, hay, and other necessary crops. It is almost certain that within a generation the ever increasing population of the United States will consume all the wheat grown within its borders, and will be driven to import, and, like ourselves, will scramble for a lion's share of the wheat crop of the world. This being the outlook, exports of wheat from the United States are only of present interest, and will gradually diminish to a vanishing point.

And :—

But if the United States, which grow about one-fifth of the world's wheat, and contribute one-third of all wheat exportations, are even now dropping out of the race, and likely soon to enter the list of wheat-importing countries, what prospect is there that other wheat-growing countries will be able to fill the gap, and, by enlarging their acreage under wheat, replace the supply which the States have so long contributed to the world's food?

First, as to the statement that additions to the wheat-growing area in the United States have diminished almost yearly since 1885. As a matter of fact, the area has distinctly diminished during the last four of the eleven years 1886–96; but in 1891 it was the highest ever reached, in 1889 and in 1892 much higher than the average, and in six of the eleven years, commencing with 1886, it was more than the average of that period. That the area should not have shown more continued increase since 1885 is what would be expected from the fact that it is just about from that date that the price of wheat has gone down so disastrously to the producer; conditions potently adverse to the extension of the area of production.[1]

As to the United States already falling out of the race, notwithstanding their increasing population, their exports of wheat were, on the average of the last five years, to 1896–97

[1] In reference to the above statements, which only come down to 1896, it may be added that according to the official returns, the average area over the four years of crop, 1893, 1894, 1895, and 1896, was only 34,544,458 acres. The officially revised figure for the crop of 1897, after a special investigation made at the close of the harvest, is, however, as quoted in *The Journal of the Board of Agriculture*, 39,465,000 acres; but the Statistician states, that no satisfactory comparison can be made between this acreage in 1897, and that for 1896, as it is believed that the returns for earlier years were under-estimated. Then, for the crop of 1898, the area is provisionally estimated at 43,000,000 acres; though it is said that the figure still awaits final confirmation. Supposing, however, the record for 1897 to be correct, and that for 1898 approximately so, it may be stated that the area for 1897 has only been exceeded twice before, and then only to a small extent; whilst that for 1898 would be more than 3,000,000 acres over any previous year. At any rate, it is admittedly very probable that the areas recorded for the immediately preceding years are too low, and it is certain that those for both 1897 and 1898, show a very great increase.

inclusive, over 3,000,000 quarters (=24,000,000 bushels) more per annum than over either of the two preceding quinquennial periods. It is true that the area of suitable land yet remaining to be brought in for the crop is comparatively not large; but there is a very wide scope for an increase of produce per acre. It should be remembered that a large proportion of the area brought under cultivation in recent years for the production and export of wheat, consists of rich prairie land, notwithstanding which the average yield per acre of the United States as a whole is only between 12 and 13 bushels, against more than twice as much, about 28 bushels, the average produce under ordinary cultivation, of the very much poorer lands of the United Kingdom. Again, the unmanured plot of the comparatively poor soil of the permanent experimental wheat field at Rothamsted, has yielded an average of more than 13 bushels per acre per annum over fifty consecutive years—that is, rather more than the average of the whole of the United States, including so much rich prairie land, and also rather more than the estimated average of the whole of the wheat lands of the world. Yet it is alleged by some that the wheat lands of the United States are already showing exhaustion.

How are these facts to be accounted for? The wheat produced in ordinary agricultural practice on the comparatively poor lands of the United Kingdom, is grown in rotation, the land is comparatively well cultivated, and it is kept comparatively free from weeds. In the case of the growth of an average of more than 13 bushels per acre for fifty years in succession without manure at Rothamsted, the land has been kept as free from weeds as is possible. On the other hand, most of the export lands of the United States are scarcely more than skimmed by the plough, scarcely any labour is bestowed on cleaning, weeds largely rob the fertility, the straw and weeds are to a great extent burnt, and manure is often wasted. These are certainly conditions well calculated to reduce fertility rapidly. But, considering the original character of a large portion of the land, much of which has not been broken up so long as, or more than, twenty years, it is impossible to believe that the wheat-growing areas of the United States, which are said to be already showing

exhaustion, would not, with good cultivation, yield large crops for many years yet; for it is not so much reduction or deficiency of fertility, but failure to utilise the existing fertility, that is the cause of the restricted yield. Improvement in this respect can, however, only be attained by an increased expenditure of both capital and labour. Upon the whole, we think there is no doubt that there still exists in the United States great inherent capability of production of wheat, not only for home consumption, but for export also, for many years to come.

As to Russia, which comes second to the United States as a wheat exporter, Sir William Crookes says that the great supply is merely provisional and precarious. He speaks of the development of the fertile, though somewhat over-rated black earth as progressing rapidly. But he adds that—"the consumption of bread in Russia has been reduced to danger point. The peasants starve and fall victims to 'hunger typhus,' whilst the wheat-growers export grain that ought to be consumed at home." At the same time, he admits that the yield per acre is extremely low. As to the low produce of the black earth, which is very low indeed, much the same argument is applicable as in the case of the low produce of the rich prairie soils of the United States. For want of proper cultivation the rich Russian soils yield much less per acre than such soils should do, and there can be no doubt that, if properly cultivated, they would yield food for the population and to spare.

With regard to Canada, Sir William Crookes speaks of—"the extent and marvellous capacity of the fertile plains of Manitoba and the North-West Provinces." But in his appendix he says:—"The most trustworthy estimates give Canada a wheat area of not more than six millions of acres in the next 12 years, increasing to a *maximum* of 12 millions of acres in 25 years." He adds that the development of this area must necessarily be slow, as the population is wanting to supply the needful labour at seed-time and harvest; whilst as population increases, so do home demands for wheat. He further adds that thus far performance had lagged behind promise, the wheat-bearing area of all Canada having increased comparatively little, and the exports not in greater

proportion. Of course, the above are only estimates of the probable development under existing conditions; but the evidence at command is to the effect that very much more than is here supposed is available for the crop whenever circumstances show that it would be profitable to devote it to the purpose. On these points Mr. Sydney C. D. Roper, who is officially connected with the subject at Ottawa, speaks of—"the existence in the North-West of the finest undeveloped wheat fields in the world." He adds, however, that at present the population is lacking, as also are lacking the immediate inducements to immigration, though a marked advance in wheat values would probably supply both the one and the other. He at the same time recognises that the appreciation of prices, when it comes, is not likely to be lasting. Lastly, in regard to the non-extension of area in Canada under existing circumstances, it is said that it is actually in contemplation to appeal to farmers to reduce their acreage under wheat in order to check over-production.

So much for the probable prospective capabilities for wheat production of the United States, Russia, and Canada. But it is safe to assert that there are very large areas suitable for the growth of the crop in other countries of the world, which have as yet been opened up only very partially, or not at all. In some cases the necessary population and labour are wanting, in some cheaper transport, in some irrigation is required, and in some more than one of these necessary conditions of success are wanting. With the low prices of recent years, however, which indicate that the supply is equal to the demand, rapid development was not to be expected. But there is no reason to doubt that, with remunerative prices, the obstacles to progress above referred to would be gradually overcome, and that the area of production would increase concurrently with the demand. In fact, the little extension of the area of production throughout the world generally in recent years is to be attributed to non-remunerative prices, and is not to be interpreted as indicating that we are approaching the limit of the available land of the world for the growth of the crop.

The dependence of the available supply of wheat on its market value may even be illustrated by what has taken

place within the present year. Sir William Crookes says that in April last the world's visible supply amounted to 10,000,000 bushels (=1¼ million quarters) less than in 1897 at the same date. We may add that it was estimated by some that the supply up to the end of the harvest year must run short of the demand, and that therefore a further rise of price was to be expected. As a matter of fact, there was a considerable rise of prices, due more to the artificial conditions bringing about the Leiter boom, than to the natural effect of supply and demand. The rise had, however, for its result, the bringing out of a great increase of supply. Thus, from the beginning of March to the end of the harvest year (the end of August), the imports of wheat into this country, though they had previously been less than in 1896–97, were this year, notwithstanding the alleged deficiency of 1¼ million quarters in April, nearly 2 million quarters more than in 1897 over the same period. Concurrently, however, from the middle of June the price gradually declined, reaching the lowest point within the twelve months at the end of the harvest year; and it has gone lower still since. This illustration of the effect of price in bringing supplies of wheat into the market is, it is true, one of only temporary and exceptional influence.

With regard to the climatic conditions essential for the successful growth of wheat, Sir William Crookes says:—"The ripening of wheat requires a temperature averaging at least 65 deg. F. for 55 to 65 days." If such were the case, we fear that so far from increasing our own area under the crop, we should have to reduce it. Thus, in neither of the five districts into which the wheat-growing area of Great Britain is divided, has either July or August, our two hottest months, shown that mean temperature in any one of the last twelve years, of higher than average produce; whilst the average mean temperature over the five districts collectively, has only reached or exceeded 60 deg. F. in four of those twelve years in July, and in only four years in August. Further, it may be stated that, at Greenwich, the mean temperature over the 50 years, from 1841 to 1890 inclusive, was only 62·5 deg. for July, and only 61·6 deg. for August; whilst the mean temperature of 55 to 65 days would be below 62·0 deg. F. It

may be added that, with the exception of 1863 and 1894, the heaviest crop of wheat, both grain and straw, grown in Great Britain during the last 50 years, was in 1854; the season of which was described as follows:—After a favourable seed time, the winter was unusually severe; the early spring was favourable, but was succeeded by cold and unseasonable weather until the middle of July, from which time until harvest, the period, though changeable, included some fine maturing and harvest weather. The harvest was, however, late. Further, the mean temperature at Greenwich was, in June, 3 deg. below the average, whilst in July it was only 61·0 deg., and in August only 61·1 deg. F.

Sir William Crookes places very little reliance on the extension of the wheat-growing area of the world. His remedy is in an increase in the yield per acre of the world's crop; and he proposes that it should be raised from 12·7 bushels as at present, to twenty bushels per acre; thus adding to the world's annual crop nearly 150,000,000 qrs. on the present area. Referring to our experiments on the continuous growth of wheat, he selects a plot on which nitrate of soda, with a full mineral manure in addition, had been employed for a number of years in succession, and from the results he calculates that it would require 22·86 lbs. nitrate of soda to produce an increase of one bushel of wheat. Accordingly, he reckons that to increase the world's crop by 7·3 bushels per acre, it would require the annual application of 1½ cwt. of nitrate of soda per acre annually. Thus, on his estimate of 163,000,000 acres under the crop, it would require 12,000,000 tons of nitrate annually to be distributed in varying amounts over the wheat-growing countries of the world; those which produce more than the average of 12·7 bushels requiring less, and those below that average requiring more. Broadly speaking, however, about 12,000,000 tons of nitrate will be required annually, in addition to the 1,250,000 tons already absorbed by the world for various crops.

Sir William Crookes proposes to manufacture the nitrate of soda required by his calculation, by oxidating the free nitrogen of the air by means of electricity, and he calculates that, by employing water power to generate the electricity, nitrate of soda could be produced for £5 per ton, and that the

Falls of Niagara are capable of supplying the required energy without much lessening their mighty flow. It may be mentioned here, that many years ago, when nitrate of soda had risen to an exorbitant price, one of us paid a visit to the late Sir Benjamin Brodie, who was carrying out experiments on the production of ozone by means of electricity, to obtain his opinion on the practicability of the production of nitrate of soda by its agency. His conclusion was that there would be no difficulty about such production, but that the cost would be too great. As we have, from 1852 up to the present time, grown very much larger crops of wheat every year than the proposed twenty bushels per acre the world over, by means of liberal applications of nitrate of soda in conjunction with the necessary mineral constituents, we have not only no objections to raise against Sir William Crookes's proposal, but we should consider a cheap supply of nitrate to be a very great boon to the agricultural world. Whether, however, an average of twenty bushels per acre would be obtained year after year the world over, by the annual application of 12,000,000 tons of nitrate of soda, we very much doubt. Sir William Crookes himself warns us that—"When we apply to the land nitrate of soda, sulphate of ammonia, or guano, we are drawing on the earth's capital, and our drafts will not perpetually be honoured." In fact, if the nitrate were used alone year after year, the available mineral constituents would soon show deficiency. Further, not only does the wheat crop thrive upon nitrate, but all the miscellaneous vegetation which infests our fields under the name of weeds, fights desperately for a share of this food, and it is only by a large and costly expenditure of labour that we can keep our fields clean enough to grow our grain crops. It is doubtless partly for this reason that much of the nitrate of soda used is employed for "cleaning-crops," roots, &c. It is also used for grass, and for spring crops such as barley or oats, rather than for wheat; as they are more easily kept free from weeds than the autumn-sown wheat. Owing to the conditions of insufficient labour under which many of the wheat crops of the world are grown, it is quite possible that the application of nitrate might in some cases result in less rather than larger crops; but probably the systems of farming may be improved before the Falls of

Niagara furnish the world with 12,000,000 tons of nitrate of soda annually.

It will be of interest briefly to compare the composition of some typical soils, so far as their richness in certain important elements of fertility is concerned. The carbon-compounds of our crops, such as the starch of grain crops and potatoes, the sugar of the sugar-cane and of roots, &c., derive their carbon either mainly or exclusively from the atmosphere, and not from the soil. We will therefore confine attention to some illustrations of the amounts of nitrogen, potash, and phosphoric acid, in our own soil compared with some rich prairie lands, and some rich Russian soils. In the case of our own soils, we have determinations of the nitrogen down to a considerable depth—sometimes to twelve times 9 in., or 108 in. in all; and we have found that some deep-rooting leguminous plants send their roots down to, and draw nitrate from, that depth. In the case of Canadian and Russian soils, however, we have only results for much less depths. Again, in the case of our own soils, the results for potash and phosphoric acid only relate to the three upper depths of 9 in. each, or 27 in. We will therefore limit our illustrations to a comparison of the amounts of the three constituents in the different soils, to a depth of 12 in. only.

First, as to the amounts of nitrogen per acre:—

Rothamsted unmanured wheat plot ..... 3,139 lb. nitrogen; corresponding to 20,058 lb. nitrate of soda.

Average of four Manitoba soils..... 10,458 lb. nitrogen; corresponding to 66,824 lb. nitrate of soda.

Average of five Russian soils..... 11,207 lb. nitrogen; corresponding to 71,609 lb. nitrate of soda.

Thus, even in the poor Rothamsted soil, the amount of combined nitrogen is very large; but, to the same depth, the quantity is, on the average, more than three times as much in the four Manitoba soils, whilst the Russian soils are richer still. These great stocks of nitrogen exist in the soils as organic nitrogen, and as such are very insoluble; but the nitrogen is gradually, though very slowly, oxidated into nitric acid, which forms with lime, soda, or other bases in the soil, very soluble salts, in which state the nitrogen becomes available to vegetation. It is estimated that the unmanured

Rothamsted wheat soil yields up an average of not more than from 20 to 25 lb.[1] of nitrogen per acre annually, notwithstanding that to the depth of 12 in. it contains 3,139 lb., corresponding to 20,058 lb. of nitrate of soda; whilst to a depth of 90 in., or 7½ ft. it contains about 15,000 lb., corresponding to about 96,000 lb. of nitrate of soda. In other fields where samples have been taken down to twelve times 9 in., or 108 in., from 15,000 lb. to 20,000 lb. of nitrogen have been found to be present down to that depth. Further, experiments in the Rothamsted Laboratory indicate that a larger proportion of the total nitrogen is readily soluble in rich garden soil, and in permanent meadow soil, than in the ordinary arable soil at Rothamsted. There can, in fact, be no doubt that under favourable conditions of cultivation the rich United States, Canadian, and Russian soils, would yield up very much more nitrogen in an available form than they have done hitherto, and also very much more than the poorer Rothamsted soil. Indeed, even under existing conditions, the Canadian soils do, on the average, yield about 1½ time as much wheat per acre as either the Rothamsted unmanured soil, or the average of the United States soils. The conclusion must be that the United States soils, especially the rich prairie soils, are capable of yielding much more wheat than they do.

Then as to the potash and phosphoric acid:—We have no results relating to these for the Canadian soils, none relating to the Rothamsted soil below 27 in., and none relating to the Russian to much more than 12 in. The following is, however, a comparison of the total amounts (as determined by strong acid), in the Rothamsted unmanured wheat soil, and (on the average) in the five Russian soils, in each case reckoned to the depth of 12 in.:—

	lbs. per Acre	
	Potash	Phosphoric Acid
Rothamsted Unmanured Wheat soil . .	8,687	3,962
Average of 5 Russian soils	61,229	5,398

Thus, there is to a depth of 12 in., about seven times as

[1] Perhaps it would be better to say 20 to 30 lb according to season.

much potash, and about one and a third time as much phosphoric acid, in the rich Russian, as in the poor Rothamsted soil. These constituents, in the condition in which they exist in soils, are, however, like the nitrogen, only slowly rendered available for vegetation.

We have not similar particulars, either for other Canadian soils, or for any United States prairie soils. We have, however, the *percentages* of nitrogen in other Canadian soils, and also in some United States prairie soils; and these show that they are very much richer in nitrogen than the Rothamsted soil. But, as we do not know the depth to which the samples were taken, we cannot estimate the amounts of nitrogen *per acre*, to a given depth. There can, in fact, be no question that these rich prairie soils are capable of yielding up much more nitrogen, and of giving much larger crops of wheat, than the Rothamsted soil.

It will be some satisfaction to those who fear that our soils are becoming exhausted to find that a soil which cannot be considered a very fertile one, and which has been under arable cultivation for some centuries, still contains such large stocks of fertility, and under good cultivation is still yielding as much wheat per acre per annum without manure, as the average of the whole of the wheat-growing lands of the world; whilst, by the aid of suitable artificial manures, it has, in one year, yielded as much as 55 bushels per acre; and has, on the average of 50 years, given much more than the average of the whole of the United Kingdom under ordinary cultivation.

What part artificial manures will play in the agriculture of the future it is difficult to foretell. Much will depend on the stores of phosphates and of potash which may be found available for use throughout the world. With regard to nitrates, as Sir William Crookes has pointed out, nitrogen exists in enormous quantities in the air in the free state, but plants require it to be supplied to them in a fixed or combined condition. Whether we go to water—as at Niagara—for the source of power, or have recourse to wind or steam, the question of a home manufacture of nitrate from the free nitrogen of the atmosphere, to supply the wants of agriculture, is a very important one. Nitrate of lime contains more nitric acid than nitrate of soda, and lime is cheaper than soda, and

nitrate of lime might prove the better manure in some cases; but its deliquescence might prove a difficulty, both in transport and use.

To sum up on the world's wheat supply:—It may be said that, whilst wheat is capable of producing very large crops under favourable conditions as to soil, climate, and manuring, it possesses a remarkable power of obtaining food from a poor soil. It can stand a considerable amount of frost, and it can thrive over an immense area of the world's surface. Although endorsing all that Sir William Crookes says as to the importance of wheat as a food, we cannot adopt his desponding views in regard to the future supplies of it. That we may have considerable fluctuations in produce and in price, the result of war, or of the vicissitudes of the seasons in different countries, is very probable; but we believe that there will always be a sufficient supply forthcoming, for those who will find the money to purchase it at a remunerative price.

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THE

FEEDING OF ANIMALS

FOR THE PRODUCTION OF

MEAT, MILK, AND MANURE,

AND FOR THE

EXERCISE OF FORCE.

BY

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INTRODUCTION AND HISTORY.

IT was shown in our paper on the Rotation of Crops, in the last number of the Journal,[1] that any explanation of the benefits of rotation is quite inadequate which does not take into account the results of the feeding of the animals on the farm. Thus, in the discussion of the amounts of the produce of the various crops grown in alternation with one another, and of the amounts of the various constituents of the individual crops, or of their separate parts, it was pointed out that only certain portions of them were at once available as saleable products; a large proportion remaining for use on the farm in some way, and only eventually yielding a profitable return.

The extent to which the retention on the farm of the constituents accumulated in the crops may take place may usefully be illustrated by reference to a particular example, which will convey a clearer conception of the importance of the subject than any mere general statement can do. Accordingly, in Table I. is given an approximate estimate of the proportion of

[1] Journal, R.A.S.E., 3rd Series, vol. v. (Part IV.), 1894, pp. 585–646.

certain selected constituents of the crops grown in the typical four-course rotation of swedish turnips, barley, leguminous crop, and wheat, which would be at once sold off the farm, and of the amounts retained upon it; supposing that only the grain of the cereals is sold, and that the root crop, the leguminous crop, and the straw of the cereals, are retained for further use. The estimates are founded on the average amounts of produce obtained, over eight courses, in the fully manured rotation, the particulars of which were given and discussed in the paper on Rotation above referred to.

TABLE I.—*Illustration of the Proportion of the Constituents of Crops grown in Rotation at once sold off the Farm, and of those retained upon it for further use.*

—	Per cent. of total in the crops	
	At once sold off the farm	Retained on the farm for further use
Dry matter	30·6	69·4
Nitrogen	43·4	56·6
Total mineral matter (ash) . .	14·5	85·5
Phosphoric acid	56·2	43·8
Potash	20·0	80·0

It is true that the exact figures given in the table have only reference to a particular case, and that in practice there will sometimes be larger and sometimes smaller proportions of these constituents of the crops at once sold, or retained on the farm. Nevertheless, the illustrations may be taken as essentially typical, and as so far conveying a very useful impression on the subject.

Referring to the figures, the question arises: To what beneficial or profitable purposes are about two-thirds of the total vegetable substance grown—more than half its nitrogen, nearly half its phosphoric acid, and about four-fifths of its potash—retained on the farm? Briefly stated, it is *for the feeding of animals for the production of meat, milk, and manure, and for the exercise of force—that is, for their labour.* It is, then, the facts, and the principles, involved in the feeding of the animals of the farm for these various purposes that we have now to consider.

It is obvious that, so long as a country is only sparsely populated, and the needs of the people are amply supplied under a comparatively rude system of agriculture, in which extended area precludes the necessity for improved methods, there would be little either of scope or of inducement to study economy in

the feeding of animals, or to systematic practice in regard to it. But as population increases in proportion to area, there arises the necessity for increased production over a given area. It was pointed out in our paper on Rotation that, in our own country, gradually a greater variety of crops came to be grown; that first leguminous crops, and then root crops, were introduced, and finally the system of rotation became general. Thus, a much greater variety, and a much greater quantity, of home-produced stock-foods became available; and in time foods of various kinds were imported from other countries.

Somewhat similar changes in their food resources occurred in various parts of the continent of Europe; and with these came the inducement, if not the necessity, to pay more attention to the subject of feeding. The end was, however, sought to be attained by somewhat characteristically different methods in our own country and on the Continent. With us, more special attention was paid to the improvement of the breeds of the farm animals themselves; not only to enhance the development of the most valuable characters in the final product, but to secure early maturity, and thus materially to economise the expenditure of food in the mere maintenance of the living meat-and-manure-making machine. As to the use and adaptation of different foods, but little systematic inquiry was undertaken in regard to it, each feeder relying largely on his own judgment, or on the unwritten rules adopted in his locality, as the result of practical experience.

On the Continent, however, and especially in Germany, much more attention was paid to the character of the food than to that of the animal; and towards the end of the last century and the beginning of this much was devoted to determining the comparative values of different foods; and tables were constructed in which, adopting hay as the standard, it was attempted to arrange all other foods according to their supposed value compared with that standard. The plan was to give the amount of each food which it was estimated was equivalent in food-value to 100 parts of hay.

The first comprehensive tables of *hay values* were constructed by Thaer, and were published by him in 1809. His operations, experiments, and writings, were of an essentially practical character. His estimates of so-called "hay values" seem, however, to have been based to some extent on the determinations of the supposed nutritive contents of different foods which had been made by Einhof; but partly also on his own determinations, and partly on direct feeding experiments. In these he sought to ascertain how much of the respective foods was required

to substitute a given quantity of hay in the daily ration of the animals. His estimates were, at any rate, controlled by such experiments, and he states that their results upon the whole tended to confirm the conclusions arrived at by analysis.

Other writers also published tables of hay values, or hay equivalents, of foods. In some of these the results of new experiments, sometimes analytical, and sometimes practical, were embodied; but it is obvious from the identity of the figures in many cases that they were largely compilations one from another.

Such was the condition of knowledge on the subject when Boussingault commenced his investigation of it soon after 1830. Like Thaer, Boussingault had the advantage of being a practical agriculturist; but whilst Thaer looked at the question of the feeding of the animals of the farm almost exclusively from the practical point of view, Boussingault approached it mainly from that of the chemist and the physiologist, though he, at the same time, made direct experiments with farm animals, and so arranged and conducted them as not only to elucidate some points of special scientific interest, but also to afford data which might serve both for the explanation and for the improvement of agricultural practice.

Thus, besides contributing much towards a better knowledge of the actual and comparative value of different foods, he investigated the question whether animals either availed themselves of the free nitrogen of the air as a source of some of their nitrogen, or eliminated either free or combined nitrogen by the lungs or skin; also whether the fat stored up by the fattening animal was exclusively derived from the already formed fat of the food, or whether it was produced within the body, from other constituents of the food.

From the point of view of the practical agriculturist, Boussingault seems fully to have assumed the utility of attempting to arrange stock-foods according to their nutritive value compared with that of hay as a standard; and, in fact, this idea has given a direction to much subsequent investigation also.

The first great advance made by Boussingault was, however, to determine the nitrogen in a large number of different foods; and, taking the amount of it as for the time the best measure of nutritive value, on this basis to compare them with hay. That is to say—supposing 100 parts of average good hay to contain a certain amount of nitrogen, how much of each of the other foods would be required to supply the same amount of it? These amounts would, on the supposition adopted, represent the quantities by weight in which one food may be substituted for

another, and they may be considered as the theoretical equivalents of 100 of hay. Accordingly, he determined the nitrogen in about seventy-six different descriptions of food, which at that date involved a truly enormous amount of labour.

Further, he selected a few typical articles of food for comparative feeding experiments, so as to be able to compare the results obtained both with those indicated by theory according to their contents of nitrogen, and with the estimates of others, founded chiefly on somewhat similar practical trials. He obviously fully recognised the difficulties and uncertainties of such modes of experimenting, and took great care to obviate error arising from them.

He discussed the general results of some experiments with milking cows; but gave in some detail the particulars and results of ten experiments with the horse. The normal food being hay, straw, and oats, he in one case substituted half the hay by potatoes, in another by Jerusalem artichokes, in another by mangel, in another by ruta-baga, and in another by carrots. Again, in another the straw and oats were replaced by potatoes; in another half the hay was replaced by more oats and straw, and so on. In each case he noted the change in weight, and in the condition of the animals in other respects, if any; and he judged accordingly, whether the amount of food given in substitution was too much or too little, and whether, therefore, the practical or the theoretical results were the most to be relied upon.

He brought together in a table [1] the estimates of the value, compared with 100 of hay, of the seventy-six different articles of food according to the amount of nitrogen he found in them; and side by side he gave the hay value of the foods according to the published estimates of others, and to the results of his own practical trials.

Subsequently, however, Boussingault was not satisfied with his results so obtained, and he pointed out that what was still wanting was the determination of the amount of the various non-nitrogenous constituents also, and of how much of them was digestible, and how much indigestible; and eventually he determined in ninety different food-stuffs, not only the nitrogen, but the mineral matter, the woody fibre or cellulose, the fatty matter, and (probably by difference) the remaining non-nitrogenous matters, which he recorded as starch, sugar, and allied bodies. As to the nitrogen, he still, as formerly, multiplied the amount found by 6·25 to represent albumin, legumin, or casein.

He also still took 100 parts of hay as the standard by which

[1] *Rural Economy*, &c. (English Edition), 1845. H. Baillière, London.

to compare the nutritive value of other foods; as, for ruminants and horses, he considered it a good standard food, and that the relation in it of the nitrogenous and the digestible non-nitrogenous constituents was fairly normal. He now, however, modified the meaning of the equivalent arrived at, by taking into account the amount of digestible non-nitrogenous substance associated with the standard amount of nitrogen in each case; and, if there were a deficiency, he stated how much of some food rich in digestible non-nitrogenous matters should be added to complete the equivalent, and so make it comparable with the 100 of hay. Indeed, he now laid it down that equivalent rations must contain equal amounts of digestible non-nitrogenous as well as of the nitrogenous bodies.

In the case of the ninety descriptions of food which he analysed as above referred to, he gave a table[1] recording the results obtained, and then showed the amount of each food required to contribute the same quantity of nitrogenous substance as 100 of hay. Next, he calculated how much nutritive non-nitrogenous matter, reckoned as carbohydrate of 42 per cent. carbon, was supplied in the amount of each food containing the nitrogen of 100 of hay. If the amount were less than in 100 of hay, he calculated how much straw was required to supply the deficiency, assuming straw to contain 45 per cent. of such matter. The final result showed, not only the same amount of nitrogenous, but as much of digestible non-nitrogenous substance also, as 100 of hay. If, however, the nitrogen equivalent of the food contained an excess of digestible non-nitrogenous constituents, he did not make any corresponding deduction from the ration.

Boussingault fully recognised that food equivalents so calculated are only satisfactory in comparing foods of the same description, which he classified generally as follows:—

1. Hays and straws.
2. Roots and tubers.
3. Oily seeds.
4. Cereal grains, leguminous seeds, oilcake, &c.

He pointed out that when the application of the tables is thus limited, they are very useful in showing how one food may be advantageously substituted for another of the same class, according to relative abundance, cheapness, and so on.

In conclusion in regard to Boussingault: in giving a sketch of the history of the progress in our knowledge of the subject of the feeding of the animals of the farm, it was only due to him to give prominence to his enormous, painstaking,

[1] *Économie Rural*, Deuxième Édition, 1851, vol. ii., pp. 356–363. Paris.

and most conscientious labours in regard to it. This is the case, independently of any direct applicability of his results and conclusions at the present time, because he was essentially the pioneer, and his conceptions and methods have had a very marked influence on the direction of subsequent investigations.

It was in 1842, that is, after Boussingault's first systematic discussion of the subject, but before his second, that Liebig published his work entitled *Chemistry in its Applications to Physiology and Pathology*. In it he treated of food in its relations to the various exigencies of the animal body; and, apparently impressed, as was Boussingault, with the fact that nitrogenous constituents were both essential and characteristic of the animal body, and that they must therefore be supplied in the food they consumed, and, in the case of the herbivora, in vegetable food-stuffs, he also, like Boussingault, indeed, probably directly influenced by his results and conclusions, himself concluded that the comparative values of food-stuffs as such were, as a rule, measurable by their richness in the nitrogenous, rather than in that of the non-nitrogenous constituents—that is to say, more by their flesh-forming than by their more specially respiratory or fat-forming capacities. Thus he says (p. 45):—

> Chemical researches have shewn, that all such parts of vegetables as can afford nutriment to animals contain certain constituents which are rich in nitrogen; and the most ordinary experience proves that animals require for their support and nutrition less of these parts of plants in proportion as they abound in the nitrogenous constituents.

Again, at p. 369 of the third edition of his *Chemical Letters* (1851) he says:—

> The admirable experiments of Boussingault prove, that the increase in the weight of the body in the fattening or feeding of stock (just as is the case with the supply of milk obtained from milch cows), is in proportion to the amount of plastic constituents in the daily supply of fodder.

Liebig would probably be somewhat biassed in favour of the conclusion here stated by the view he held—that the amount of force exercised in the animal body was measurable by the amount of nitrogenous substance transformed, and this again by the amount of urea found in the urine. To Liebig's views on this latter point, as well as on the question of the sources in the food of the fat of the animal body, and on some other points of scientific as well as practical interest, reference will be made further on, when considering each of these several questions independently. In the meantime our special object is to show, what were the prevailing opinions on the subject of the adaptation of foods, according to their composition, to the sum of the requirements of the animals of the farm, which include,

done in our interpretation of the results, due reservation is made as to the character, both of the so-reckoned nitrogenous, and of the non-nitrogenous organic substance, of the different foods, the indications are very clear and significant as to whether, taking our fattening food-stuffs as they go, their comparative food-value is measurable, more by their contents in digestible nitrogenous, or in digestible non-nitrogenous constituents.

The investigations also involved the determination of the composition, and especially of the amounts and the proportion of the nitrogenous, and of the non-nitrogenous constituents, in the bodies of the animals themselves, and in their increase whilst fattening; and it also involved that of the composition of the excrements, that is, of the manure.

Thus, the inquiry embraced the following points:—

1. The amount of food, and of its several constituents, consumed in relation to a given live-weight of animal, within a given time.

2. The amount of food, and of its several constituents, consumed to produce a given amount of increase in live-weight.

3. The proportion, and relative development, of the different organs or parts of different animals.

4. The proximate and ultimate composition of the animals, in different conditions as to age and fatness; and the probable composition of their increase in live-weight during the fattening process.

5. The composition of the solid and liquid excreta (the manure) in relation to that of the food consumed.

6. The loss or expenditure of constituents by respiration and the cutaneous exhalations—that is, in the mere sustenance of the living meat-and-manure-making machine.

7. The yield of milk in relation to the food consumed to produce it; and the influence of different descriptions of food on the quantity, and on the composition, of the milk.

As already said, several hundred animals—oxen, sheep, and pigs—have been submitted to experiment.

The amount, and the relative development, of the different organs or parts were determined in 2 calves, 2 heifers, 14 bullocks, 1 lamb, 249 sheep, and 59 pigs.

The percentages of water, mineral matter, fat, and nitrogenous substance, were determined in certain separated parts, and in the entire bodies, of 10 animals—namely, 1 calf, 2 oxen, 1 lamb, 4 sheep, and 2 pigs. Complete analyses of the ashes, respectively of the entire carcasses, of the mixed internal and other 'offal' parts, and of the entire bodies, of each of these ten animals, have also been made.

From the data provided, as above described, as to the chemical composition of the different descriptions of animal in different conditions as to age and fatness, the composition of the increase whilst fattening, and the relation of the constituents stored up in the increase to those consumed in food, have been estimated.

To ascertain the composition of the manure in relation to that of the food consumed, oxen, sheep, and pigs, have been experimented upon.

The loss or expenditure of constituents, by respiration and the cutaneous exhalations, has not been determined directly, that is by means of a respiration apparatus, but only by difference; that is, by calculation, founded on the amounts of dry matter, ash, and nitrogen, in the food, and in the (increase) fæces and urine.

Independently of the points of inquiry above enumerated, the results obtained have supplied data for the consideration of the following questions:—

1. The sources in the food of the fat produced in the animal body.

2. The characteristic demands of the animal body (for nitrogenous or non-nitrogenous constituents of food) in the exercise of muscular power.

3. The comparative characters of animal and vegetable foods in human dietaries.

Food Consumed and Increase Produced.

It is proposed, first to consider the results illustrating the amounts of food, and of its nitrogenous and non-nitrogenous constituents respectively, consumed by a given live-weight of animal within a given time, and the amounts required to produce a given amount of increase in live-weight. The illustrations will be drawn from experiments with sheep and with pigs.

The Experiments with Sheep.

Table II. shows, for each of three series of experiments with sheep, in the first three columns the amounts of nitrogenous, of non-nitrogenous, and of total organic substance, *consumed per* 100 *lb. live-weight per week*, and in the last three columns the amounts *consumed to produce* 100 *lb. increase in live-weight*. The figures represent the quantities of the crude constituents consumed; that is, the amounts of nitrogenous substance calculated by multiplying the nitrogen by 6·3, which implies that the whole of it exists in the foods as albuminoids, which admittedly is not the case. It will be seen, however, that this method is quite sufficient for the purposes of the

illustrations at present in view; though it is frequently far from accurate in the case of unripened vegetable products, and it is especially so in that of succulent foods, such as feeding roots. The amounts of crude non-nitrogenous substance are calculated by deducting those of the mineral matter, and of the crude nitrogenous constituents, from those of the total dry matter consumed. Here again, it is admitted that the results are only approximations to the truth; but it will be seen that, as in the case of the nitrogenous constituents, they are nevertheless quite sufficient for the purposes of our present illustrations. The crude total organic matter is simply the sum of the nitrogenous and non-nitrogenous calculated as above.

TABLE II.—*Experiments with Sheep made at Rothamsted in* 1850. *Nitrogenous and Non-nitrogenous constituents consumed per* 100 *lb. live-weight per week; and to produce* 100 *lb. increase in live-weight.*

Pens	Limited food	*Ad libitum* food	Per 100 lb. live-weight per week			To produce 100 lb. increase in live-weight		
			Nitrogenous	Non-nitrogenous	Total organic	Nitrogenous	Non-nitrogenous	Total organic
SERIES 1. 5 SHEEP IN EACH PEN (14 WEEKS).								
1	Linseed-cake	Swedish turnips	2·46	9·85	12·31	167	650	817
2	Oats		1·57	11·36	12·93	103	684	787
3	Clover chaff		1·64	13·12	14·76	102	736	838
4	Oat-straw chaff		1·07	10·17	11·24	102	913	1,015
		Mean	1·68	11·13	12·81	118	746	864
SERIES 2. 5 SHEEP IN EACH PEN (19 WEEKS).								
1	Linseed-cake	Clover chaff	3·78	12·93	16·71	321	1,103	1,424
2	Linseed		3·21	12·66	15·87	289	1,144	1,433
3	Barley		2·58	13·79	16·37	235	1,269	1,504
4	Malt		2·52	14·02	16·55	266	1,457	1,723
		Mean	3·02	13·35	16·38	278	1,244	1,521
SERIES 3. 5[1] SHEEP IN EACH PEN (10 WEEKS).								
1	Barley	Mangel	1·70	10·59	12·29	118	731	850
2	Malt and malt dust		1·64	10·12	11·76	111	677	788
3	Barley (steeped)		2·08	12·60	14·68	121	730	851
4	Malt and dust (steeped)		1·77	10·70	12·47	136	821	958
5	Malt and dust (extra quantity)		1·89	11·63	13·52	126	776	903
		Mean	1·82	11·13	12·94	123	747	870

[1] Only four sheep in pens 1, 3, and 4.

Referring to the results, it is impossible to go into any detail here. A glance at the figures in the first three columns of the Table (II.) relating to the amounts of the constituents *consumed per* 100 *lb. live-weight per week* is sufficient to show that, in all comparable cases, there was much more uniformity in the amounts of the non-nitrogenous than in those of the nitrogenous substance consumed for a given live-weight of the fattening animal within a given time. The deviations from this general regularity in the amount of non-nitrogenous substance consumed are, indeed, in most cases such that, when they are examined, they tend clearly to show that the uniformity would be considerably greater if the amounts of only the really available respiratory and fat-forming constituents had been represented, instead of those of the crude or total non-nitrogenous substance consumed.

As pointed out in our earlier papers, in reading the figures allowance has obviously to be made, both for those of the non-nitrogenous constituents which would probably become at once effete, and also for the different respiratory and fat-forming capacities of the portions which are digestible. Thus, comparing series with series, the amounts are higher in Series 2, where the *ad libitum* food was clover chaff containing a large amount of indigestible fibre, than in either of the other series, where it consisted of Swedish turnips or mangel wurzel. Then, the quantity consumed was higher in the third pen of Series 1, with clover chaff, than in the other pens of the same series; and it was lower in pen 1 of Series 1, with linseed cake containing much oil; and it was again lower in pens 1 and 2 of Series 2, also with much fatty matter in the food, than in the other pens of the same series with cereal grain.

Indeed, when we bear in mind the various circumstances which must tend to modify the indications of the actual figures, it will be admitted that the coincidences in the amounts of available respiratory and fat-forming constituents consumed by a given weight of animal within a given time, are much more striking and conclusive than, considering the views prevalent on the subject at the time, could have been anticipated.

With this general uniformity in the amounts of the *non*-nitrogenous substance consumed by a given live-weight within a given time, the amounts of the nitrogenous constituents so consumed are, on the other hand, seen to vary under the same circumstances in the proportion of from one to two, or three, or more.

Let us now refer to the last three columns of Table II., which show the amounts of the respective constituents

consumed to produce 100 *lb. increase in live-weight.* In considering these results we must, as when discussing those relating to the consumption by a given live-weight within a given time, read the indications of the actual figures as modified by the obviously different capacities, for the purposes of the animal economy, of the substances the amounts of which they are assumed to represent. It must also be borne in mind, that the proportion of real dry substance in the increase of the animal will vary to some extent according to the character of the food. For example, it will be rather the less, the more succulent the food, and the greater, the greater the proportion of fat in the increase. Again, as in the case of the results showing the consumption for a given live-weight of the fattening animal within a given time, the figures represented the demand, not only for respiration, and for maintenance in other respects, but also that for increase in live-weight, so now those specially arranged to show the relation of consumption to increase, at the same time include the amounts required by the exigencies of respiration and maintenance.

Taking a general view of the results, which is all that can be done here, it is seen that where clover chaff, with its large amount of indigestible woody fibre, was used as the *ad libitum* food, the total amount of non-nitrogenous substance consumed to produce a given increase in live-weight was much greater than where the *ad libitum* food consisted of roots. Due allowance must, therefore, be made for this in comparing the results of one series with those of another. Doing this, it is obvious that the amounts of really available non-nitrogenous substances consumed were, at any rate, much more nearly uniform in the different series, and in the different pens, than were those of the nitrogenous substance. Of the differences that would still remain, most would be again reduced by making allowance for the different respiratory and fat-forming capacities of the remaining available non-nitrogenous constituents; since, for example, much less of fatty matter would be required than of starch or sugar, or of the pectine compounds of the roots.

Again, as in the case of the consumption by a given live-weight within a given time, so now in that of the consumption to produce a given amount of increase, there is a much wider range of difference in the amounts of the nitrogenous than of the non-nitrogenous constituents consumed; and the differences are, as before, much greater than can be explained by the differences in the character of the nitrogenous substances which the figures represent in the different cases.

Thus, then, the results of these experiments with sheep, when interpreted with due regard to the known differences in the character of the nitrogenous and non-nitrogenous constituents in the different foods, fully justify the conclusions drawn from them more than forty years ago:—namely, that taking food-stuffs as they go, it is their supply of the digestible non-nitrogenous, that is of the more specially respiratory and fat-forming constituents, rather than that of the nitrogenous or specially flesh-forming ones, that regulates both the amount of food consumed by a given live-weight of animal within a given time, and the amount of increase in live-weight produced.

But as it seems to have been tacitly assumed in recent years, since much attention has been paid to the investigation of the digestibility of the different constituents of foods, that conclusions founded on the determined amount in the foods of the crude substances only cannot be relied upon, we have had the whole of our early results, both with sheep and with pigs, re-calculated, making correction, as far as practicable, for the amounts of the constituents in the different foods which are assumed to be indigestible, or otherwise not of food-value, according to the Tables given by Emil von Wolff in the edition of his work published in 1888. He there gives, for nearly 200 different articles of stock foods, the percentages of water, mineral matter (ash), crude protein, crude fibre, non-nitrogenous extractive matters, and crude fat; and then the percentages of digestible albuminoids, digestible carbohydrates, and digestible fat. In applying his data to our results, the amount of the crude substance in each description of food is reduced in the proportion which his figures show of crude to digestible in the same description of food. Further, in the case of the so estimated amounts of digestible fatty matter, the figure obtained has been multiplied by 2·4 to bring it approximately to its equivalent of carbohydrate, the amount then being added to the other digestible non-nitrogenous substance, so reckoning the whole as carbohydrate. Lastly, as Wolff makes no correction for the non-albuminoid condition of a large portion of the nitrogen in succulent roots, it has been assumed, in accordance with results obtained at Rothamsted and elsewhere, that in Swedish turnips only 45 per cent., and in mangel only 40 per cent., of the total nitrogen will exist as albuminoids.

There are obvious objections to some of the modes adopted for the determination of the digestible constituents of the various foods, which render them inapplicable, without considerable reservation, to the estimate of the amounts of the constituents which will probably be actually digested in the case of ordinary

liberal rations. But, if accepted as approximations only, they undoubtedly afford useful data for some general conclusions.

Neither space nor time will permit of either the record or the discussion of the re-calculated tables. It must suffice here to say, that the results as so re-calculated—that is, making correction, as far as present knowledge permits, for the probable amounts of the indigestible or non-available constituents of the various foods—not only fully confirm the conclusions drawn on a careful study of the circumstances of the experiments, and of their results, more than forty years ago, but they bring out the points then maintained still more clearly to view.

The Experiments with Pigs.

Let us next see whether experiments with pigs lead to similar conclusions. The pig requires much less bulk in his food than the ruminant. His food, and especially his fattening food, consists, weight for weight, of a much larger proportion of digestible or convertible constituents, and contains very little effete woody fibre. Thus, whilst the food of oxen and sheep is composed principally of grass, hay, straw, and roots, with a comparatively small proportion of grain, leguminous seeds, or other concentrated foods, that of the pig consists largely of grain or other seeds, which contain a comparatively small amount of indigestible woody fibre, and a large proportion of starch or other digestible carbohydrate, and nitrogenous matters which are almost entirely in the condition of albuminoids. It is true that the pig consumes also more or less of starchy tubers, or saccharine roots, which contain a considerable proportion of their nitrogen in other forms than albuminoids. But the more rapidly he is fattened, the larger is the proportion in his food of starchy grains, or other ripened seeds.

Notwithstanding the much more concentrated and digestible character of the food of the fattening pig, he consumes a much larger quantity of dry substance in proportion to his weight than either the ox or the sheep. In these circumstances he yields much more increase, both in proportion to a given live-weight within a given time, and to a given amount of dry substance of food consumed. This is clearly illustrated in Table IV., p. 35, which shows, as an approximate average, that, per 100 lb. live-weight per week, the fattening ox will consume about 12·5 lb. of dry substance of food, and yield about 1·13 lb. of increase; the sheep will consume about 16 lb. of dry substance of food, and yield about 1·76 lb. of increase; whilst the pig, on the other hand, will consume about 27 lb.

of dry substance of his more concentrated food, and yield about 6·43 lb. of increase. Indeed, compared with oxen or sheep, the liberally fed fattening pig will consume much more food in excess of that required for the respiratory function and for mere maintenance, so that the amounts of non-nitrogenous matters consumed for a given live-weight within a given time represent in less proportion the respiratory requirements, and in a greater proportion those for increase.

Numerous feeding experiments have been made at Rothamsted with pigs. In 1850, Series 1, with twelve pens, Series 2, also comprising twelve pens, and Series 3, with five pens; and subsequently a fourth Series of four pens was made. The general plan was to give, in one or more pens, food of high or of low percentage of nitrogen as the case might be, *ad libitum*; then in others to give a fixed and limited amount of food of low percentage of nitrogen, and *ad libitum* a food of high percentage; or a fixed and limited amount of food of high percentage of nitrogen, and *ad libitum* a food of low percentage, and so on; and as the *ad libitum* food always supplied much the larger proportion of the total ration, the animals fixed their own consumption, according to the composition of the foods, and to their own requirements; including those both for respiration and maintenance, and for increase.

The foods of high percentage of nitrogen consisted in most cases of an equal mixture of bean- and lentil-meal, that is of highly nitrogenous leguminous seeds; and those of low percentage were, in most cases, either maize-meal or barley-meal. In some, however, either pure starch or pure sugar was given. The details of the foods, the weights and increase of the animals, and of the amounts of the various foods, and of their nitrogenous and non-nitrogenous constituents consumed, per 100 lb. live-weight per week, and to produce 100 lb. of increase in live-weight, have been given and fully discussed in various papers.[1]

The conclusion drawn from the results of the various experiments with pigs was that, in their case, as in that with sheep, it was the supplies in the food of the available non-nitrogenous or total organic constituents, rather than those of the available nitrogenous substance, that regulated the amount consumed, both by a given live-weight within a given time, and to produce a given amount of increase. The point is, however, even more clearly brought to view by the graphic representation of the results given in the coloured diagrams following page 102.

[1] "On the Composition of Foods in relation to Respiration and the Feeding of Animals" (*Rep. Brit. Assoc.* for 1852); "Pig Feeding" (Journal, R.A.S.E., vol. xiv. (1853), p. 459).

In explanation of them it may be stated that nitrogenous substance is represented by black, non-nitrogenous by yellow, and total organic substance by red. Diagram I. illustrates the relative amounts of the respective constituents consumed per 100 lb. live-weight per week; and Diagram II. the amounts consumed to produce 100 lb. increase in live-weight. Each of the thirty columns represents the results of a separate experiment or pen.

The first nine columns show the results of experiments 1–8, and 12, of Series 1; the next twelve, those of the twelve experiments of Series 2; the next five, those of the five experiments of Series 3; and the last four, those of the four experiments of Series 4. It may be added that there were three pigs in each pen of Series 1, 2, and 4, and four in each pen of Series 3.

The plan of the diagrams in other respects will be best understood by giving an example. Take, for instance, the amounts of nitrogenous substance consumed per 100 lb. live-weight per week, as represented in black, in the left-hand division of Diagram I. The lowest amount so consumed throughout the thirty experiments was in pen 5; and that amount is taken as 100, and as the standard by which to compare the amounts consumed in the other pens; and it will be seen that, in the case of this pen 5, the colouring does not extend above the base-line, which is numbered 100 in the column of figures given at each side of the diagram. It will be further seen, that the figures range up to 300; and that, for example, in the case of pen 1 the black colouring extends above the 300 line. That is to say, there were more than 300 parts of nitrogenous substance consumed in that pen, against only 100 in pen 5. In like manner, the height of the colouring for each of the other pens represents the proportion of nitrogenous substance consumed in that pen, compared with the amount in pen 5 taken as 100.

Exactly the same plan is adopted in representing the relative amounts of non-nitrogenous, and of total organic substance, consumed in the different pens. Thus, the lowest amount of non-nitrogenous substance consumed per 100 lb. live-weight per week was in pen 10, which is therefore represented as 100, and the relative amounts consumed in the other pens are represented by the different heights of the yellow colouring above the 100 base-line.

Again, of total organic substance consumed per 100 lb. live-weight per week, the lowest amount was in pen 23, and the greater amount so consumed in each of the other pens is repre-

sented by the height above the base-line of the red colouring in each case.

It need only be added that precisely the same plan is followed in the construction of Diagram II., which shows the relative amounts of the substances consumed in the different experiments to produce 100 lb. increase in live-weight.

Referring to the results, and first to those represented in Diagram I., which shows the relative amounts consumed per 100 lb. live-weight per week, a glance brings strikingly to view the fact, that there was no uniformity whatever in the amounts of nitrogenous substance so consumed in the thirty different cases, representing as many different rations. Indeed, it is seen that the amounts ranged in the proportion of 100 to more than 300; with very great variation between these amounts. The range in the non-nitrogenous substance so consumed is, on the other hand, very much less; reaching in but few cases from 100 to 150. Lastly, in the case of the total organic substance the range is less still.

Next, referring to Diagram II., showing the relative amounts of the different constituents consumed to produce 100 lb. increase in live-weight, there is again no uniformity in the amounts of nitrogenous substance so consumed. There is, however, great uniformity in the amounts of the non-nitrogenous substance consumed; and there is, in the majority of cases, about the same uniformity in those of the total organic substance consumed.

It should be understood that, in these diagrams relating to pigs, as in the table relating to the experiments with sheep, it is the amounts of the crude nitrogenous, the crude non-nitrogenous, and the crude total organic substance, as determined by the methods of analysis already described, and which were the only ones practicable at the time, that are represented. Of course, therefore, the indications of the actual results have, as in the case of those with sheep, to be interpreted with due regard to the known facts in each case. But, to meet objection, we nearly twenty years ago re-calculated the results, and re-constructed the Diagrams, making correction for indigestible or non-available constituents in the various foods, in accordance with the then published Tables of Professor Emil von Wolff; and more recently, as in the case of the experiments with sheep, we have had them again re-calculated according to his subsequently revised Tables, already referred to.

It may be stated that the diagrams, as first re-constructed, entirely confirmed the conclusions previously drawn; and, indeed, illustrated the points brought out by those at first, and now again given, even more strikingly still. That is, they showed

a wider range in the amounts of the nitrogenous substance consumed in the different experiments; with one or two easily explained exceptions, a less variation in the amounts of the non-nitrogenous substance; and especially a less range in the amounts of total organic substance consumed. The two methods showed, moreover, with some obviously necessary exceptions, comparatively little difference in what is called the "*nutritive ratio*," that is the relation of the non-nitrogenous to the nitrogenous constituents. As it is impossible on this occasion to give and discuss both sets of results, it seems best, after this explanation, to adhere to the originally obtained and recorded results which led to the conclusions arrived at so long ago, rather than to adopt corrections based upon factors as yet not sufficiently established. Nevertheless, it is satisfactory to find that, applying the best methods of correction which subsequent investigations suggest, the conclusions formerly drawn are confirmed and emphasized, rather than in any way vitiated or modified.

In conclusion in regard to this branch of the subject:—It must be considered established, that, taking ordinary food-stuffs as they go, neither the amount consumed in relation to a given live-weight of the animal within a given time (which of course in the fattening animal covers the requirements for increase as well as for sustenance), nor the amount consumed to yield a given amount of increase in live-weight (which covers the requirements for sustenance also), was at all in proportion to the amount of the nitrogenous constituents supplied. It is, on the other hand, obvious that the consumption, both for sustenance and for increase, was much more nearly in proportion to the amount of the digestible and available non-nitrogenous constituents supplied; but, that it was more nearly still regulated by the amount of the total digestible organic substance—nitrogenous and non-nitrogenous together—which the foods supplied. The indication is, indeed, as will be more clearly seen further on, that, if there be a deficiency of available non-nitrogenous constituents, an excess of the nitrogenous may to a certain extent take the place of the non-nitrogenous; that, in fact, within certain limits, the two classes of constituents may, for the purposes of respiration and fat-formation, mutually replace each other.

When the character of the main products of respiration, and the prominence, in a quantitative sense, of the respiratory function in the maintenance of the body, are considered, it seems only what might be expected, that the consumption by a given live-weight of animal within a given time, should be regulated, more by the supplies in the food of the oxidable non-nitrogenous, than of the nitrogenous or more specially flesh-forming con-

stituents; and now that it is known, as will further on be shown is the case, that, in the exercise of force the respiratory action is enormously increased, whilst that of nitrogenous transformation is but little augmented, the result is rendered still more consistent and intelligible.

That the increase in live-weight of the animal should (provided the food be not abnormally poor in nitrogenous substances), also be regulated more by the supplies of the non-nitrogenous than of the nitrogenous or flesh-forming constituents, does not at first sight seem so intelligible.

There is, however, no doubt of the fact, that our current fattening rations are, *as such*, more valuable in proportion to their richness in digestible and available non-nitrogenous, than to that of their nitrogenous, constituents. At the same time, as the manure is valuable largely in proportion to the nitrogen it contains, there is, so far, an advantage in giving a food rich in nitrogen, provided it is in other respects a good one, and, weight for weight, not much more costly. But, since in recent years the vegetable products most benefited by nitrogenous manures have been so largely imported as much to reduce the value of the home-grown crops, even this advantage of highly nitrogenous food-stuffs is becoming of less importance, and that of having the best food for the progress of the animal one of more and more consideration.

The question obviously suggests itself, Of what does the increase of the animal chiefly consist? To experimental evidence on this point attention will next be directed.

Composition of Oxen, Sheep, and Pigs, and of their Increase whilst Fattening.

It is proposed to show the composition of some of the animals of the farm in different conditions as to age and fatness; to estimate the probable composition of their increase in live-weight during the fattening process; and to show the relation of the constituents in the increase to those consumed in the food. The results which have been obtained will also afford data for the discussion of the question of the sources in the food of the fat produced in the animal body; they will, further, supply evidence as to the composition of the manure in relation to that of the food consumed; and lastly, they will lead to a consideration of the characteristic food-requirements of the body in the exercise of force.

To determine the ultimate composition, and in a sense the proximate composition also, of oxen, sheep, and pigs, and under

such conditions that the results obtained should serve as data for the estimation of the probable composition of their increase whilst growing and fattening, ten animals were selected for analysis, namely:—a fat calf, a half-fat ox, and a fat ox; a fat lamb, a store sheep, a half-fat old sheep, a fat sheep, and an extra-fat sheep; a store pig, and a fat pig.

Table III. (p. 25) shows the percentage of mineral matter, of nitrogenous compounds, of fat, of total dry substance, and of water—in the upper division in the collective carcass parts, in the middle division in the collective offal parts (excluding contents of stomachs and intestines), and in the lower division in the entire bodies of the ten animals. The weight of the contents of stomachs and intestines is also given.

It may, in the first place, be observed that, comparing one animal with another, all the results tend to show a prominent connexion between the amount of total mineral matter and that of the nitrogenous constituents of the body; there being a general tendency to a rise or fall in the percentage of mineral matter, with the rise or fall in that of the nitrogenous compounds.

Comparing the composition of the different carcasses, it is seen that there was, in every instance excepting that of the calf, a considerably higher percentage of fat than of total nitrogenous substance.

In the carcass of even the store or lean sheep there was more than one and a half times as much fat as nitrogenous substance; and in that of the store or lean pig there was twice as much. In the carcass of the half-fat ox there was one-fourth more fat than nitrogenous matter; and in that of the half-fat old sheep there was more than twice as much.

Of the fatter animals, those assumed to be in a suitable condition for sale as human food, the carcass of the fat ox contained twice and one-third as much, that of the fat sheep four times, and that of the very fat sheep even six times, as much fat as nitrogenous substance. Lastly, in the carcass of the moderately fat pig, there was nearly five times as much fat as nitrogenous compounds.

Turning now to the second division of the Table (III.), which shows the composition of the collective offal parts (excluding contents of stomachs and intestines), the figures do not show such a uniform tendency to a diminution in the percentage of mineral matter coincidently with that of the nitrogenous substance as the animal matures, as was observed in the case of the carcasses. This, however, is doubtless due to the fact that the ash of the offal parts includes adventitious matter adhering to the pelt, hair, or wool, which it was impossible entirely to remove.

TABLE III.—*Percentage Composition of the Carcasses, the Offal, and the Entire Bodies, of Ten Animals, of different Descriptions, or in different Conditions of Maturity.*

Description of animal	Mineral matter (ash)	Nitrogenous substance	Fat	Total dry substance	Water	Contents of stomachs and intestines (in moist state)
PER CENT. IN CARCASS.						
Fat calf	4·48	16·6	16·6	37·7	62·3	—
Half-fat ox	5·56	17·8	22·6	46·0	54·0	—
Fat ox	4·56	15·0	34·8	54·4	45·6	—
Fat lamb	3·63	10·9	36·9	51·4	48·6	—
Store sheep	4·36	14·5	23·8	42·7	57·3	—
Half-fat old sheep	4·13	14·9	31·3	50·3	49·7	—
Fat sheep	3·45	11·5	45·4	60·3	39·7	—
Extra-fat sheep	2·77	9·1	55·1	67·0	33·0	—
Store pig	2·57	14·0	28·1	44·7	55·3	—
Fat pig	1·40	10·5	49·5	61·4	38·6	—
Means of all	3·69	13·5	34·4	51·6	48·4	—
PER CENT. IN OFFAL (EXCLUDING CONTENTS OF STOMACHS AND INTESTINES).						
Fat calf	3·41	17·1	14·6	35·1	64·9	—
Half-fat ox	4·05	20·6	15·7	40·4	59·6	—
Fat ox	3·40	17·5	26·3	47·2	52·8	—
Fat lamb	2·45	18·9	20·1	41·5	58·5	—
Store sheep	2·19	18·0	16·1	36·3	63·7	—
Half-fat old sheep	2·72	17·7	18·5	38·9	61·1	—
Fat sheep	2·32	16·1	26·4	44·8	55·2	—
Extra-fat sheep	3·64	16·8	34·5	54·9	45·1	—
Store pig	3·07	14·0	15·0	32·1	67·9	—
Fat pig	2·97	14·8	22·8	40·6	59·4	—
Means of all	3·02	17·2	21·0	41·2	58·8	—
PER CENT. IN THE ENTIRE ANIMAL (FASTED LIVE-WEIGHT).						
Fat calf	3·80	15·2	14·8	33·8	63·0	3·17
Half-fat ox	4·66	16·6	19·1	40·3	51·5	8·19
Fat ox	3·92	14·5	30·1	48·5	45·5	5·98
Fat lamb	2·94	12·3	28·5	43·7	47·8	8·54
Store sheep	3·16	14·8	18·7	36·7	57·3	6·00
Half-fat old sheep	3·17	14·0	23·5	40·7	50·2	9·05
Fat sheep	2·81	12·2	35·6	50·6	43·4	6·02
Extra-fat sheep	2·90	10·9	45·8	59·6	35·2	5·18
Store pig	2·67	13·7	28·3	39·7	55·1	5·22
Fat pig	1·65	10·9	42·2	54·7	41·3	3·97
Means of all	3·17	13·5	28·2	44·9	49·0	6·13

It is seen that the percentage of nitrogenous substance is in every case but one greater, and that of the fat very much less, in the collective offal than in the collective carcass parts. In the case of oxen and sheep, a large amount of the nitrogenous substance of the offal is in the non-consumable portions—the pelt, hair or wool, and hoofs; whilst some of the remainder is in the stomachs and intestines, which are only very partially consumed, and the rest in other parts which are more generally consumed, namely—the head flesh, with tongue and brains, the heart, the liver, the pancreas, the spleen, the diaphragm, and sometimes the lungs.

Lastly, in regard to the composition of the collective offal parts, it is seen that they contain a higher percentage of nitrogenous substance, a lower percentage of fat, and a lower percentage of total dry substance, and consequently a larger proportion of water, than the collective carcass parts.

It is obviously a matter of interest, both from a dietetic point of view, and as showing what proportion of the gross product of the feeding process is saleable as human food, to consider what proportion of the fat, and of the nitrogenous substance, of the slaughtered animals will, on the average, be consumed as human food in one form or another. The result of much inquiry leads to the conclusion that, in our own country, on the average, the whole of the carcass fat, and about one-fifth of the offal fat, of oxen will be consumed; that of sheep, an amount equal to the whole of their carcass fat will be consumed; and that of the pig, an amount equal to the whole of its carcass fat, and, in addition, more or less of its offal fat, will be sold and consumed as food.

Calculation leads to the conclusion, that about one-sixth of the whole of the nitrogenous matter of the collective offal parts of oxen will, on the average, be consumed, but that the whole of the nitrogenous matter reclaimed as food from the offal parts will fall short of the amount contained in the bones of the carcass. So nearly, however, will these quantities balance one another, especially if a portion of the gelatine from the carcass-bones be consumed, that it may be assumed that, of the total nitrogenous substance of the bodies of these animals, only about as much as, or very little more than, is represented by the total amount in the carcasses, will be consumed. In the case of pigs, however, a larger proportion of the total nitrogenous substance of the body will be consumed than in that of the other animals; but, as the Table shows, the percentage of total nitrogenous substance is less, and that of the fat much greater, in the pig than in the other animals.

Upon the whole, therefore, it would seem that the proportion

of the consumed fat to the consumed nitrogenous substance will, on the average, be greater than its proportion in the total carcasses of the fattened animals. Such is pretty certainly the case in our own country; but the relations are admittedly far otherwise in the United States, and it is, to say the least, very questionable whether the difference is to the advantage of the consumers in that country.

Let us now turn to the lower division of the Table (III.), showing the composition of the entire bodies of the animals, which, of course, represents the gross product of the feeding process. It is this, therefore, that is of most interest to the farmer to consider in connexion with the composition of the food expended in its production.

As was the case in the carcasses, there is also in the entire bodies a marked diminution in the percentage of mineral matter as the animal matures. Judging from the results of the analyses of the ashes of the animal bodies, it may be stated in general terms, that about, or rather more than, 40 per cent. of the total mineral matter of the animals is phosphoric acid. In the case of oxen and sheep, nearly 45 per cent., and in that of pigs about 40 per cent., will be lime; whilst of potash, the ash of oxen and sheep will probably contain from 5 to 6 per cent., and that of pigs 7 to 8 per cent. or more.

Of total nitrogenous compounds, as well as of total mineral matter, oxen seem to contain, in parallel conditions, a rather higher percentage than sheep, and sheep rather more than pigs. It is seen that the entire body of the fat calf contained about $15\frac{1}{4}$, that of a moderately fat ox $14\frac{1}{2}$, of a fat lamb $12\frac{1}{3}$, of a fat sheep $12\frac{1}{4}$, of a very fat one about 11, and of a moderately fattened pig also about 11 per cent. of nitrogenous substance. The store or lean animals contained from 2 to 3 per cent. more than the moderately fat ones.

The figures show, on the other hand, that fat constitutes by far the largest item in the dry or solid matter of the entire bodies of the animals; especially of those fit for slaughtering as human food. Even the half-fat ox contained about 19 per cent. of fat, or more than of nitrogenous substance. The entire body of the store sheep also contained nearly 19 per cent. of fat, that is, several per cent. more than of nitrogenous substance; that of the half-fat old sheep $23\frac{1}{2}$ per cent., or more than $1\frac{1}{2}$ times as much as of nitrogenous substance; and that of the store pig also more than 23 per cent. of fat, and about $1\frac{2}{3}$ times as much as of nitrogenous substance.

Of the fattened animals, the entire body of the fat ox contained rather more, and that of the fat lamb rather less, than 30

per cent. of fat; that of the fat sheep 35½ per cent., of the very fat sheep 45¾ per cent., and that of the fat pig about 42 per cent. of fat. The fat calf, however, contained even rather less than 15 per cent. of fat.

Thus the entire bodies, even of store or lean animals, may contain more fat than nitrogenous compounds, whilst those of fattened animals may contain several times as much. That of the fat ox contained more than twice as much, that of the moderately fat sheep nearly three times, of the very fat sheep more than four times, and of the moderately fattened pig about four times, as much fat as nitrogenous substance.

In conclusion on this point—all the experimental evidence concurs in showing, that the so-called *fattening* of animals is properly so designated. During the feeding or fattening process the percentage of the total dry substance of the body is considerably increased; and the fatty matter accumulates in much larger proportion than the nitrogenous substance. It is evident, therefore, that the *increase* of the fattening animal must contain a lower percentage of nitrogenous substance, and a higher percentage of both fat and total dry substance, than the entire body of the animal.

It is obvious, however, that the results of the analyses of the ten animals do not supply data directly applicable for the estimation of the composition of animals in the very various conditions in which they are dealt with in practice, or of their increase over any given period under varying conditions of feeding. Accordingly, we have constructed tables founded on the analytical results above referred to, showing the probable average percentage composition of the different descriptions of animal, each at eight gradationary points, from the store to the very fat condition; and the factors thus obtained have been applied for the calculation of the composition of the increase in a number of cases of ordinary practice, or of direct experiment in which the weights of the animals at the commencement and at the conclusion of a fixed period, the general character of the food they consumed, and their final condition, were more or less fully known. It is admitted that these eight conditions do not cover all the variations of composition occurring in actual practice; but at the same time there can be no doubt that by the aid of such factors the feeder would be enabled to calculate, with sufficient approximation to the truth for all practical purposes, the composition of the store animals he buys or sells, and of the fat ones he sells. At any rate, we believe that the results are the best that existing knowledge enables us to provide.

It is impossible to go into any detail here, either as to the

composition of the animals at the different stages, or as to the estimated composition of their increase, but the results may be briefly summarised as follows:—

In the case of oxen, the figures representing the composition of the animals at different stages of progress show—that the percentage of mineral matter ranged from 5·15 in the store to only 3·43 in the very fat condition; that of the nitrogenous substance from 18·0 in the store to only 13·1 in the very fat state; and that of the fat increased from 11·7 in the store to 37·4 in the very fat condition. Again, the percentage of total dry substance increases from only 34·8 in the store to 54·0 in the very fat condition. Lastly, the percentage of water decreases from the store to the very fat condition.

The parallel results for sheep show that the percentage of mineral matter ranges from 3·25 in the store to only 2·90 in the very fat animal; the nitrogenous compounds from 15·5 per cent. in the store to only 10·9 per cent. in the very fat condition; and against these reductions the fat increases from 14·5 per cent. in the store to 45·8 per cent. in the very fat condition; and the total dry substance from 33·2 per cent. to 59·6 per cent. There is, therefore, a lower percentage of total dry substance in the store sheep than in the store ox, owing to the less amount of mineral and nitrogenous matter in the store sheep. There is, on the other hand, a higher percentage of dry substance in the very fat sheep than in the very fat ox, owing to the higher percentage of fat in the sheep. Lastly, in the sheep, the percentage of water diminishes from the earliest to the latest stage from 60·8 to only 35·2.

The results relating to the composition of pigs showed a reduction in the percentage of mineral matter from 2·93 in the store to only 1·14 in the very fat condition; and a reduction in that of nitrogenous substance from 14·4 in the store to 9·5 in the very fat state. But, instead of a reduction, there is an increase in the percentage of fat from 18·6 in the store to 51·6, or to more than half the weight of the body, in the very fat condition; and there is an increase in the percentage of total dry substance from 35·9 in the store to 62·2 in the very fat condition; and (excluding contents of stomachs, &c.) a reduction in the percentage of water from 58·6 to 34·4.

It may be observed that in no case do the percentages of total dry substance and of water make up 100; the difference being represented by the contents of stomachs and intestines, the amounts of which found in the animals actually analysed are taken as the basis of the estimates for the amounts in the other conditions, just as in the case of the other constituents of the body.

Let us next summarise very briefly the results of the application of these data as to the composition of the animals in different conditions, for the purpose of estimating the composition of their increase in passing from one condition to another.

First, referring to oxen, the composition of their increase during the feeding process has been estimated in the case of the recorded results of actual practical feeding, in some cases of large numbers of animals, and over considerable periods of time. Other cases have been those of results obtained at Rothamsted, or under Rothamsted superintendence, mostly in direct feeding experiments, but sometimes in the feeding of animals in the ordinary practice of the farm.

Reviewing the whole of the results, the indication was, that the composition of the *increase* of moderately fattened oxen during a final fattening period of several months will contain about, or little more than, 1½ per cent. of mineral matter, seldom more than 7 to 8 per cent. of nitrogenous substance and seldom as little as 60, and generally nearer 65 per cent. of fat; whilst the total dry substance of the increase will generally range from 70 to 75 per cent. In the case, however, of oxen fattened very young, and the feeding period extending over a much longer time, similar calculations lead to the conclusion that the growing and fattening increase of such animals may contain perhaps 2¼ per cent. or more of mineral matter, against only about 1½ per cent. over a limited final period of more purely fattening increase; about 10 per cent. of nitrogenous substance, against only 7 to 8 per cent. in the only fattening increase; and perhaps only from 50 to 55 per cent. of fat, against from 60 to 65 per cent. in the more exclusively fattening increase. In fact, whilst the growing and fattening increase would consist of about two-thirds dry substance and one-third water, that of the more purely fattening increase would consist of nearly three-fourths dry substance and only about one-fourth water.

Similar results relating to sheep lead to the conclusion that during a final period of some months of feeding on good fattening food, their increase will generally contain not less than 2 per cent. of mineral matter, and frequently more; that is, distinctly more than in the case of oxen, the quantity largely depending on the amount of wool. Of nitrogenous substance, the final fattening increase of sheep will probably seldom contain more than 7 per cent., and frequently somewhat less. In other words, notwithstanding the large amount of nitrogen in the wool of sheep, their fattening increase will probably generally contain less nitrogenous substance than that of oxen. On

the other hand, the increase of well-fed and moderately fattened sheep will generally contain nearly, and sometimes more than, 70 per cent. of fat, against an average of less than 65 per cent. in the case of oxen; and in the case of very fat sheep the percentage of fat in the increase may even reach 75 per cent.

Upon the whole, it may be assumed that the increase of liberally fed and moderately fattened sheep, over several months of final fattening, will probably consist of about 2 per cent. of mineral matter, about, or less than, 7 per cent. of nitrogenous substance, and from 65 to 70 per cent. of fat; and in all, of from 75 to 80 per cent. of total dry substance; whilst the increase over the final period of excessive fattening may contain from 70 to 75 per cent. of fat, and from 80 to 85 per cent. of total dry substance.

Referring to pigs, the increase of those liberally and suitably fed for fresh pork will probably, on the average, contain—an immaterial amount of mineral matter, only from 6½ to 7½ per cent. of nitrogenous substance, from 65 to 70 per cent. of fat, and from 70 to 75 per cent. of total dry substance. The increase over the last few months of high feeding of pigs fed for curing will, however, probably contain lower percentages of nitrogenous substance, but higher, and sometimes considerably higher, percentages of both fat and total dry substance. The tendency of the demand in recent years has, however, been for less excessively fat bacon than formerly.

Thus far, then, it has been shown, that the amounts of food, or of its various constituents, consumed, both for a given live-weight of animal within a given time, and to produce a given amount of increase, were very much more dependent on the quantities of the non-nitrogenous, than on those of the nitrogenous constituents, which the food supplied. It has been said, that when the large requirement for non-nitrogenous constituents of food to meet the expenditure by respiration is borne in mind, it need not excite surprise that consumption in relation to a given live-weight within a given time should be so largely measurable by the amount of digestible and available non-nitrogenous substance which the food supplies; but that, at first sight, it was less intelligible that the quantities consumed to produce a given amount of increase in live-weight should also be much more dependent on the supplies of the non-nitrogenous, than on those of the nitrogenous, constituents of the food.

The results relating to the chemical composition of the different animals, in different conditions as to age and maturity, have shown, however, that even store animals may contain as

much, or even more, of the non-nitrogenous substance—fat—than of nitrogenous substance; whilst the bodies of fattened animals may contain two, three, four, or even more times as much dry fat as dry nitrogenous matter. It has further been shown, that the proportion of fat to nitrogenous substance in the *increase in live-weight* of the fattening animal is much higher than in the entire bodies of the fattened animals. If, therefore, the non-nitrogenous substance of the increase—the fat—is derived from the non-nitrogenous constituents of the food, the relatively large demand for such constituents for the production of fattening increase would seem to be amply accounted for.

The important question arises, therefore, What are the sources in the food of the fat of the fattening animal? In other words, from what constituent or constituents in the food is the fat produced?

Sources in the Food of the Fat produced in the Animal Body.

Prior to the publication of Liebig's work on *Organic Chemistry in its Applications to Physiology and Pathology*, in 1842, it seems to have been assumed that the Herbivora derived their fat from ready-formed fatty matters in their food; and that the Carnivora derived theirs from the ready-formed fat of the animals they consumed. Liebig argued that, as a rule, the food consumed by the herbivora did not contain sufficient fatty matter for the purpose; and he maintained that, although fat might be formed from the nitrogenous substance of the food, its main source was the starch, sugar, and other carbohydrates, which the food supplied.

Dumas and Boussingault[1] at first called in question the view that fat was produced in the animal body, and assumed that the food of the herbivora supplied sufficient fatty matter to account for the whole of the fat stored up. Subsequently, however, Dumas and Milne-Edwards,[2] from the results of experiments with bees, Persoz[3] from experiments with geese, and Boussingault[4] from those with pigs, geese, and ducks, concluded that fat was formed from the carbohydrates of the food. At the same time Boussingault considered that, in normal feeding, the amount of albuminoids consumed would generally supply sufficient carbon for the production of the fat formed by the animal.

Next came the evidence of the Rothamsted experiments, the

[1] *Balance of Organic Nature*, 1844, p. 116 *et seq.*
[2] *Compt. Rend.* vol. xvii. p. 531.
[3] *Ann. Chim. Phys.* vol. xiv. p. 408 *et seq.*
[4] *Ibid.* vol. xiv. p. 419 *et seq.*; vol. xviii. p. 444 *et seq.*

majority of which were conducted within the years 1848–1853 inclusive. They involved feeding experiments on between 400 and 500 animals, with foods of known composition; the slaughter, determination of the weights of the parts, and noting on the character, as to fatness, &c., of more than 300 animals; and finally, the chemical analysis of ten animals.

In the first place, it was clearly demonstrated that much more fat was stored up in the bodies of the fattening animals than could be derived from the ready-formed fatty matter in their food. Secondly, from a careful study of the enormous amount of experimental data obtained, as well as of the known facts of practical experience in feeding, it was considered no doubt whatever could be entertained that much, if not the whole, of the fat formed in the bodies of the herbivora fed for the production of meat was derived from the carbohydrates of the food.

In fact, the experimentally determined relation of the non-nitrogenous, and of the nitrogenous constituents of the food, respectively, to the amount of increase produced; the composition of fattening increase generally; the relatively greater tendency to grow in frame and to form flesh with highly nitrogenous food; the greater tendency to form fat with food comparatively rich in non-nitrogenous substances, and especially in carbohydrates; and common experience in feeding—all pointed in the same direction.

For some years there was little or no discussion on the subject, and it seemed to be tacitly admitted, both on the Continent and in this country, that the views of Liebig, as to the formation of at any rate much of the fat of the herbivora from carbohydrates, were correct.

In 1865, however, at a meeting of a Congress of Agricultural Chemists held at Munich in August of that year, Professor Voit, from the results of experiments made in Pettenkofer's respiration apparatus, with dogs fed chiefly on flesh, maintained that fat must have been produced from nitrogenous substance; and that this was probably the chief, if not the only, source of the fat even of herbivora.

Pettenkofer and Voit further maintained, that to establish the formation of fat from the carbohydrates, experiments must be brought forward in which the fat deposited was in excess of that supplied by the food, *plus* that which could be derived from the transformation of albumin.

Of course, the mere fact that the food consumed contained enough nitrogenous substance for the formation of all the fat that had been produced would of itself be no proof that that

substance had been its exclusive source. On the other hand, if the amount of fat stored up in the animal was in excess of that which could be derived from the ready-formed fatty matter of the food, and from the transformation of the nitrogenous substance, it would be proved that at any rate some of the stored-up fat must have had another source—and this could only be the carbohydrates.

Accordingly, the results of many of the Rothamsted feeding experiments were calculated to ascertain whether or not the ready-formed fat and the nitrogenous substance of the food were sufficient to account for the whole of the fat estimated to have been stored up. None of the experiments had been specially arranged with a view to the elucidation of this question. In some of them, however, what may be called minimum amounts, and in others excessive quantities, of nitrogenous substance, had been consumed. Some of the results seemed to us to afford clear evidence on the point, and we gave a paper on the subject in the Physiological Section, at the Meeting of the British Association for the Advancement of Science at Nottingham, in 1866; and it was published, in abstract in the *Report of the British Association* for 1866, and in full in the *Philosophical Magazine* for December of that year. And as it is upon the results as then given that any subsequent discussion of our conclusion has been founded, it is proposed, in the first place to consider the evidence afforded by those results; but afterwards to adduce certain modifications of some of them, in order to bring them more into accord with recent knowledge on some points, and to meet more effectively objections that have been raised against the conclusions drawn from them.

The first point to consider was, What description of animal is likely to yield the most direct and conclusive results on the subject? Obviously the one which is fed more especially with the view to the production of fat; which consumes in its most appropriate fattening food a comparatively low proportion of nitrogenous substance, and a comparatively high proportion of carbohydrates; and which yields a large proportion of fat, both in relation to the weight of its body within a given time, and to the amount of food consumed. The following Table (IV.) briefly summarises the results of very numerous experiments with oxen, sheep, and pigs, so far as they illustrate the comparative characters of the different descriptions of animal in regard to the points above enumerated.

In the first place, it is to be observed, that although the proportion of intestines and contents is greater, that of the stomach and contents is very much less, in the pig than in

either of the ruminants—as also is that of the stomachs and contents, and intestines and contents, taken together; the percentage of these collectively being, in oxen 14·3, in sheep 10·9, and in pigs only 7·5, of the weight of the body. The fact is, that the appropriate fattening food of the pig consists of ripened seeds, and highly starchy roots, containing but little indigestible fibre, whilst that of the ruminants contains a considerable amount of slowly digestible or indigestible cellulose, and often a much greater amount of indigestible or unassimilable nitrogenous substance. The result is, that a less proportion of the live-weight of the pig consists of more or less effete matter retained in the alimentary organs.

TABLE IV.—*Showing the Comparative Fattening Qualities of different Animals.*

—	Oxen	Sheep	Pigs
RELATION OF PARTS IN 100 LIVE-WEIGHT.			
Average of	16	249	59
Stomach and contents	11·5	7·4	1·3
Intestines and contents	2·8	3·5	6·2
	14·3	10·9	7·5
Internal loose fat	4·6	7·0	1·6
Heart, aorta, lungs, windpipe, liver, gall-bladder and contents, pancreas, spleen, and blood	7·0	7·3	6·6
Other offal parts	13·0	15·0	1·1
Total offal parts	38·9	40·2	16·8
Carcass	59·3	59·7	82·6
Loss by evaporation, &c.	1·8	0·1	0·6
Total	100·0	100·0	100·0
PER 100 LIVE-WEIGHT.			
Dry substance consumed in food per week	12·5	16·0	27·0
Increase yielded per week	1·13	1·76	6·43
PER 100 DRY SUBSTANCE OF FOOD.			
Fat in increase	5·2	7·0	15·7
Total dry substance in increase	6·2	8·0	17·6
Total dry substance in excretions	36·5	31·9	16·7
AVERAGE FAT PER CENT.			
In lean condition	16·0	18·0	22·0
In fat condition	30·0	33·0	44·0
In increase whilst fattening	60·0	65·0	70·0

Then, the second division of the table shows, that with the much higher character of its food, and the much less proportion of it indigestible and effete, the pig both consumes very much more, and yields very much more increase, for a given live-weight within a given time.

Lastly, as is shown in the third division of the table, for 100 *of dry substance of food consumed*, the pig yields very much more, both of fat and of dry substance in increase; and, on the other hand, voids very much less of dry substance in urine and in fæces.

Thus, as compared with either oxen or sheep, the pig offers many advantages as a subject for the consideration of the relations of food and increase, and consequently for that of the source in the food of the fat which he yields. He has a less proportion of alimentary organs and contents; he consumes more food in proportion to his weight; he yields a larger proportion both of total increase and of fat; and finally, much less of his food is effete and voided. The general result is, that changes in his live-weight are in a much less proportion influenced by variations in the contents of the alimentary organs, and are, therefore, much truer indications of change in the substance of the body; and hence the range of error in calculating the amount and composition of his increase in relation to the amount and composition of the food consumed is much less.

The Experiments at Rothamsted with Pigs.

In the selection of the experiments with pigs, for calculating whether more fat was stored up than could possibly have been derived from the ready-formed fat and the nitrogenous substance of the food, some have been taken in which the proportion of the nitrogenous to the non-nitrogenous constituents of the food was abnormally high, and others in which it was fairly normal, or even low. In all cases, the experiments were conducted for periods of not less than eight or ten weeks; and the amounts, both of total increase, and of fat stored up, were so large in proportion both to the original weight of the animal, and to the amount of food consumed, that the data obtained may safely be relied upon for the settlement of the question at issue.

In the upper portion of the next Table (V.) are recorded some particulars of the nine experiments selected for calculation, namely—the description of the food, the number of animals experimented upon, the duration of the experiment, the original and final live-weights, the increase per head and on 100 original weight, the percentage of carcass in fasted live-

weight, and the amount of crude non-nitrogenous to 1 of crude nitrogenous substance in the food.

The middle division of the table shows, *for* 100 *increase in live-weight*—the amount of nitrogenous substance consumed in the food, the amount of it estimated to be stored up in the increase, and the quantity remaining, and therefore possibly available for the formation of fat. Next there are given—the estimated amount of fat in the increase, the amount ready-formed in the food, and the difference—that is, the amount newly-formed. There are then given—the amounts of carbon in the estimated newly-formed fat, the amounts in the available nitrogenous substance *minus* that in the urea formed, supposing the whole of the nitrogen not stored up in increase to contribute to such formation; and lastly, the difference, that is, the amount of carbon available from the nitrogenous substance for the formation of fat, more or less than that required for the amount of fat produced.

Then, in the bottom division of the table are shown, *for* 100 *of carbon in the estimated produced fat*—the amount available from the nitrogenous substance, and the amount not available from that source, in each experiment; the amount not so available representing, of course, the proportion required from other sources.

It is hardly necessary to point out that, according to the above mode of illustration, the figures show, not only the utmost proportion of the stored-up fat which could possibly have had its source in the nitrogenous substance of the food, but notably more than could possibly have been so derived. Thus, to say nothing of other considerations, it has been assumed, for simplicity of illustration, and for the sake of argument, that the whole of the nitrogenous substance of the food not stored up as increase would be perfectly digested, and be available for fat-formation; and that, in the breaking up of the nitrogenous substance for the formation of fat, no other carbon compounds than fat and urea would be produced; and lastly, that the whole of the ready-formed fatty matter of the food has contributed to the fat stored up. It is obvious, however, that these assumptions are in part improbable, and in part quite inadmissible; whilst the tendency of the error is, in each case, to show too large a proportion of the stored-up fat to have been possibly derived from the ready-formed fat, and the nitrogenous constituents, of the food.

It is obvious, therefore, that where the figures show an excess of carbon available from nitrogenous substance over that which would be required if the produced fat had been

TABLE V.—*Relation of the Total Fat in the Increase to the Ready-Formed Fatty Matter in the Food, and of the Carbon in the Fat produced within the Body to that in the Nitrogenous Substance consumed, in Experiments with Fattening Pigs.*

Experiments	1	2	3	4	5	6	7	8	9
	Bean-meal, lentil-meal, and bran, each 1 part, barley-meal 3 parts	Bean-meal, lentil-meal, bran, and maize-meal, each *ad lib.*	Mixture, equal parts bran and lentil-meal *ad lib.*	Maize-meal *ad lib.*	Barley-meal *ad lib.*	3lb. 3 oz. lentil-meal, and 9 oz. bran, per head per day and— Sugar *ad lib.*	Starch *ad lib.*	Sugar and starch, each *ad lib.*	Lentil-meal, bran, sugar, and starch, each *ad lib.*
CONDITIONS, AND ACTUAL RESULTS OF EXPERIMENTS.									
Number of animals	1	3	3	3	3	3	3	3	3
Duration of experiment—weeks	10	8	8	8	8	10	10	10	10
Original live-weight per head, lb.	103	143	147	144	149	95	95	94	97
Final live-weight per head, lb.	191	228	248	217	246	178	178	184	201
Increase in live-weight per head, lb.	88	85	101	73	97	83	83	90	104
Increase on 100 original weight	85·4	59·7	68·9	51·3	64·9	86·4	87·0	96·8	106·8
Per cent. carcass in live-weight	82·8	83·9	81·9	85·4	—	83·1	80·1	81·7	80·8
Non-nit. sub. to 1 nit. sub. in food (crude)	3·6	3·3	2·0	6·6	6·0	4·1	4·1	4·7	3·9
PER 100 INCREASE IN LIVE-WEIGHT.									
Nitrogenous substance: In food	100·0	107·0	138·0	57·0	64·0	81·0	81·0	74·0	83·0
Nitrogenous substance: In increase	7·8	6·1	6·7	5·3	6·5	7·5	7·6	8·0	8·2
Available for fat formation	92·2	100·9	131·3	51·7	57·5	73·5	73·4	66·0	73·8
Fat: In increase	63·1	73·9	69·6	79·0	71·2	64·1	63·9	62·0	59·9
Fat: In food	15·6	20·4	11·2	26·3	12·4	7·9	7·9	7·8	6·6
Newly formed	47·5	53·5	58·4	52·7	59·8	56·2	56·0	54·7	53·3
Carbon: In newly-formed fat	36·6	41·2	45·0	40·6	45·3	43·3	43·1	42·1	41·0
Carbon: In available nit. sub. *minus* urea	44·0	48·1	62·6	24·7	27·4	35·1	35·0	31·5	35·2
More (+) or less (−) in nit. sub. than required	+7·4	+6·9	+17·6	−15·9	−17·9	−8·2	−8·1	−10·6	−5·8
PER 100 CARBON IN ESTIMATED NEWLY-FORMED FAT.									
Carbon: In available nit. sub. *minus* urea	120·2	116·7	139·1	60·8	60·5	81·1	81·2	74·8	85·9
Carbon: Not available from nitrogenous substance	—	—	-	39·2	39·5	18·9	18·8	25·2	14·1

formed from it, the excess is over-estimated; and, on the other hand, that where they show a deficiency of nitrogenous substance for such formation, the deficiency is under-estimated; so that, in fact, the amount of fat required to be derived from other sources would be greater than the figures indicate. Indeed, according to the mode of calculation adopted, 100 of nitrogenous substance would yield 62 parts of fat; but it has been fully admitted in subsequent discussions, that at most 51·4 parts of fat could possibly be derived from 100 parts of proteid substance; and more recently a much lower figure has been adopted.

After these general remarks, we may now turn to the consideration of the results of the different experiments.

In experiment 1, two pigs of the same litter, of almost exactly equal weight, and, as far as could be judged, of similar character, were selected. One was killed at once, and the amount of total dry or solid matter, of nitrogenous substance, of fat, and of mineral matter, determined in it. The other was then fed for a period of ten weeks on a mixture consisting of—bean-meal, lentil-meal, and bran, each 1 part, and barley-meal 3 parts, given *ad libitum*. It was then weighed, killed, and its composition determined as in the case of the other animal. In fact, the object of the experiment was, to determine the composition of a "*store*" and of a "*fat*" pig, and to estimate the composition of its increase whilst fattening; and the data thus provided have formed the basis of the estimate of the fat in the increase, not only in the case of experiment 1, to which they directly apply, but in that of each of the other eight experiments, the results relating to which are recorded in the table. On this point it may be observed that, taking into consideration the weight and condition of the animals at the commencement, the character of the foods, the length of the fattening period, the proportion of increase upon the original live-weight, and the final condition of the animals, it may perhaps be concluded, that the tendency of error in the calculations would be to give the proportion of fat in the increase somewhat too high in experiments 2 and 3, and somewhat too low in experiments 6, 7, 8, and 9. In experiments 4 and 5, however, the animals were the fattest in the series; and it will be seen further on, that the high estimates of fat in the increase in their case are probably not too high—indeed, in experiment 5 even somewhat too low.

It might be supposed that, at any rate in the case of experiment 1, the results would be admirably adapted for our present purpose. But that experiment was made in 1850, that is nearly 45 years ago, and before we had acquired sufficient evidence against the view then prevailing, namely, that

the increase of the fattening animal was largely dependent on the richness of the food in nitrogenous constituents; and everybody having experience in the fattening of pigs will admit that, in this case, the food was much more highly nitrogenous than is recognised as most favourable for the fattening of the animal. In fact, it is seen that the proportion of the crude non-nitrogenous to 1 of crude nitrogenous substance in the food was only 3·6, instead of about 6, as in barley-meal. There was, therefore, an excess of nitrogenous substance consumed.

Referring to the middle division of the table, the calculated results show that, *for* 100 *increase in live-weight*, 100 of nitrogenous substance was consumed in the food. Of this, it is estimated that only 7·8 parts were stored up in the increase, leaving 92·2 parts available for the possible formation of fat.

It is next seen, that the 100 of increase was estimated to contain 63·1 parts of fat, whilst the food supplied only 15·6 parts, leaving, therefore, at least 47·5 parts to be produced within the body. The figures show that this would require 36·6 parts of carbon, whilst 44·0 parts are estimated to have been available from the nitrogenous substance of the food; leaving, therefore, according to the mode of calculation adopted, 7·4 parts more carbon available than were required for the formation of the produced fat. Or, as shown in the bottom division of the table, *for* 100 *carbon in the estimated newly-formed fat*, 120·2 parts were available from the nitrogenous substance consumed in the food.

Here, then, the calculations afford no evidence that fat must have been produced from carbohydrates. But, as already explained, the mode of estimate adopted assumes the whole of the ready-formed fat in the food to have been stored up, and the whole of the carbon of the nitrogenous substance, beyond that in the animal increase, and in the urea formed, to have been utilised for fat formation. Neither of these assumptions is, however, admissible; and it will be seen further on, when due correction is made in regard to these points, that even in this experiment, with so abnormally high a proportion of nitrogenous substance in the food, it is pretty certain that some of the produced fat must have had its source in the carbohydrates.

In experiment 2, the food consisted of bean-meal, lentil-meal, bran, and maize-meal, each given separately, and *ad libitum*; and in experiment 3, of an equal mixture of bean-meal and lentil-meal, also given *ad libitum*. It is seen that, in both cases, the proportion of crude non-nitrogenous to 1 of crude nitrogenous substance in the food was even lower than in

experiment 1; being, in experiment 2, 3·3, and in experiment 3, only 2·0, against 3·6 in experiment 1. Here again, as might be expected, with so high a proportion of nitrogenous substance in the food, the calculations show that there was more than sufficient carbon available from the nitrogenous substance of the food for the formation of all the fat that was estimated to be produced.

Experiments 4 and 5 show a very different result. In experiment 4, the food consisted of maize-meal alone, and in experiment 5 of barley-meal alone, in each case given *ad libitum*. In America especially, maize-meal is largely used for the fattening of pigs, almost, if not quite, alone; and in our own country barley-meal is undoubtedly recognised as the most appropriate fattening food of the animal. It is seen that, in experiment 4, with maize-meal, the proportion of crude non-nitrogenous to 1 of nitrogenous substance in the food was 6·6, and in experiment 5, with barley-meal, it was 6·0; or, in both cases, nearly that which is recognised as appropriate in the fattening food of the animal, but rather low in nitrogenous substance.

Accordingly, the calculations show much less nitrogenous substance consumed for the production of 100 increase in live-weight, and much less left available for fat formation, after deducting the amount estimated to be stored up in the increase. Then, as to the fat, the animals were undoubtedly much fatter than the analysed "*fat*" pig. Deducting the amounts of fat supplied in the food from that in the increase, there remained, in the one case 52·7, and in the other 58·8 parts, formed within the body, requiring in the first case 40·6, and in the second 45·3 of carbon; whilst the amounts of carbon estimated to be available from the nitrogenous substance of the food were only 24·7 and 27·4 parts; leaving, in the one case 15·9, and in the other 17·9 parts, to be provided from other constituents of the food. Or, if the calculations are made for 100 *carbon in the estimated newly-formed fat*, the figures show that in one case 39·2, and in the other 39·5 per cent., of the total carbon of the produced fat must have been derived from other constituents of the food.

In other words, even on this mode of calculation, nearly 40 per cent. of the newly-formed fat must have had its source in the carbohydrates. We shall see further on, that even a considerably larger proportion still must in reality have been so derived.

The peculiarity of the experiments 6, 7, 8, and 9 was, that the food contained less ready-formed fat than in any of the

other cases, and that a large proportion of the non-nitrogenous substance supplied was in the form either of pure starch or pure sugar, or both. In experiments 6, 7, and 8, a fixed quantity of lentil-meal and bran, averaging 3 lb. 3 oz. of lentil-meal and 9 oz. of bran, was given per head per day; and, in addition, in experiment 6 sugar *ad libitum*, in experiment 7 starch *ad libitum*, and in experiment 8 sugar and starch, each separately, *ad libitum*. Lastly, in experiment 9, lentil-meal, bran, sugar, and starch, were each given separately and *ad libitum*. It will be seen that the proportion of crude non-nitrogenous to 1 of crude nitrogenous substance was 4·1 in experiments 6 and 7, 4·7 in experiment 8, and only 3·9 in experiment 9; that is, the food contained a higher proportion of non-nitrogenous substance than in experiments 1, 2, and 3, but considerably lower than in experiments 4 and 5. Accordingly, the final result of the calculations is intermediate between that for the other two series.

To go a little into detail, it is seen that, *for* 100 *increase in live-weight*, the amount of nitrogenous substance estimated to be available for fat-formation was, in this series, intermediate between that in the other two. With much less fatty matter supplied in the food, the amount of fat estimated to be newly formed was about the same as in the other cases. The amount of carbon estimated to be available for fat-formation from the nitrogenous substance of the food was, in each case, notably less than the amount required for the production of the newly-formed fat. The indication is, therefore, that, in each case, a considerable proportion of the produced fat must have had its source in other than the nitrogenous constituents of the food.

The bottom division of the table shows that, reckoned for 100 carbon in the estimated newly-formed fat, in the first case 18·9, in the second 18·8, in the third 25·2, and in the fourth 14·1 per cent., or, on the average, about 20 per cent. of the whole, must have been derived from other sources—in fact from the carbohydrates. Nor can there be any doubt that the figures under-estimate the proportion of the produced fat which could not have had its source in the albuminoids of the food.

The general result of the whole series of experiments is, then, that when the food of the fattening animal contains an abnormally high amount and proportion of nitrogenous substance, enough of it will probably be available for the possible formation of all the fat produced in the body; but that, when the amount and proportion of such substances in the food are only normal, or low, there will remain a large proportion of the produced fat which could not have had its source in the proteids, and must have been derived from the carbohydrates.

Referring to our results and conclusions as given above, Professor Voit, in a paper which he published in 1869,[1] admits that in the experiments in which there was only a medium albuminoid supply in the food there was, as the figures stand, a considerable deficiency for the formation of the fat produced, and a still greater deficiency when the relation of the nitrogenous to the non-nitrogenous constituents was lower still; and hence it would appear that in these instances a considerable amount of fat had been derived from the carbohydrates. Still, he says, he cannot allow himself to consider that a transformation of carbohydrates into fat is proved thereby. He says he has not been able to get a clear view of the experiments from the figures recorded, and suggests several possible sources of error. He proposed that new experiments with geese and with pigs should be made; and, in a subsequent conversation one of us had with him, he expressed his willingness to undertake a conclusive experiment with pigs.

Weiske and Wildt[2] did undertake an investigation with pigs to determine the point. But one animal was fed on food so rich in nitrogen that it suffered in health, and the experiment had to be discontinued; and the other on food so poor that it fattened extremely slowly, and hence, at the conclusion, calculation showed that there was enough of the consumed nitrogenous matter available for fat formation to cover the whole of the fat which had been produced.

Professor Emil von Wolff, in his work entitled *Die rationelle Fütterung der landwirthschaftlichen Nutzthiere, auf Grundlage der neueren Thier-physiologischen Forschungen*, published in 1874, assumed that albumin was probably the exclusive source of the fat of the fattening herbivora of the farm. But he made the reservation, that the amounts of increase produced in relation to constituents consumed, which common observation showed may be obtained with pigs, and still more the results recorded of some direct experiments with those animals (presumably our own), are almost incomprehensible without assuming the direct concurrence of the carbohydrates in the formation of the fat. Nevertheless, he considered that such evidence was inconclusive, and that experiments with pigs should be made in a respiration apparatus to settle the question.

After the inconclusive results of Weiske and Wildt, and the publication of Professor Wolff's views, as above quoted, we

[1] *Zeitschrift für Biologie*, Band 5.
[2] *Zeitschrift für Biologie*, Band 10.

carefully reviewed and re-calculated many of the results of our feeding experiments, including some with oxen and with sheep, as well as those with pigs, in order to satisfy ourselves whether any doubt could be entertained of the views we had previously advocated.

The result of this examination, so far as the ruminants were concerned, was to show that, owing to the comparatively small amount of increase obtained with them from a given amount of constituents consumed, the quantity of nitrogenous substance passed through the system for the production of a given amount of increase was, in most cases, so large as to admit of the assumption that the whole of the fat formed might have had its source in transformed nitrogenous matter. As will be seen further on, however, some of the experiments with sheep showed that at any rate part of the fat stored up must have had some other source than the fatty matter and the proteids of the food.

The reconsideration of the results with pigs fully confirmed the view that, in many cases, much more fat had been produced than could possibly have been derived from transformed albumin of the food. We concluded, therefore, that we were not called upon to institute new experiments; and decided instead, again to direct attention to the results which had already been published.

Accordingly, we gave a paper on the subject, in the Section for Agriculture and Agricultural Chemistry, at the meeting of the *Naturforscher Versammlung* held at Hamburg in 1876, at which there were present a number of the chief agricultural chemists of Germany. The results given in Tables IV. and V. were discussed, and it was pointed out that, even according to the mode of calculation adopted, which would imply about 62 parts of fat to be producible from 100 parts of nitrogenous substance, experiments 4 and 5, in which the proportion of the non-nitrogenous to the nitrogenous constituents in the food was the most appropriate for fattening, showed that about 40 per cent. of the produced fat could not have had its source in the nitrogenous substance consumed; whilst if, according to Henneberg and Voit, it were assumed that 100 parts of albumin can at most yield 51·4 of fat, the results would be much more striking still. They would, of course, be still more so if, as has more recently been estimated, only 42 instead of 51·4 parts of fat can be derived from 100 of albumin.

It was next considered what amount of error in the estimates would have to be admitted to turn the scale, and to show that the whole of the produced fat might have been derived from the

albuminoids of the food. After going into considerable detail on the point, it was concluded that any such range of error was simply impossible.

Further, it was maintained that, in the case of pigs fattening rapidly on their most appropriate fattening food, the amount of fat stored up in proportion to the amount of fat and nitrogenous substance consumed was so large, that the question of whether or not the carbohydrates contribute to fat-formation might be conclusively settled by a properly conducted feeding experiment with those animals, without any analysis of the fæces or the urine, or any determination of the products of respiration. It was stated that it was only necessary to select two animals of a breed of good fattening quality, and as nearly alike as possible in character and in weight; a convenient size and weight being—say about 90 lb. per head. Each should then be fed with ground barley of good quality, giving it, by degrees, until both weighed about 100 lb. Then slaughter one, and determine its total amount of nitrogenous substance and of fat. Continue to feed the other with barley-meal (and water) exclusively, as much as it will consume, until it reaches a weight of about 200 lb.; then slaughter and analyse it as the first. The quantity and composition of the food must, of course, also be determined. Such an animal would probably consume about 500 lb. of barley, and increase in live-weight from 100 to 200 lb., in from eight to ten weeks—more or less, according to the quality of the animal, the quality of the food, and other conditions. It was desirable that the animals selected should have been feeding on fairly good food previously, so that the transition to full fattening food should not be too sudden. It was also, of course, desirable that the experiments should be made in duplicate if possible.

In the discussion which followed, Professor Henneberg, who was, we believe, the first to have a Pettenkofer respiration apparatus constructed for experimenting with the larger animals of the farm, and had perhaps, at that time, conducted more experiments on feeding than any other agricultural chemist in Germany, said he did not doubt the formation of fat from carbohydrates in the case of pigs. He added, that probably sooner or later the carbohydrates would be restored to their former position so far as fat-formation in other animals was concerned, for already some experiments had shown that such formation was quite close upon the limits of the amount possibly derivable from the fat and albuminoid matters of the food. Professor Emil von Wolff also spoke in the same sense so far as pigs were concerned.

Since that time experiments have been made on the subject in Germany with various animals; but, even in those with pigs, the conditions above indicated as desirable, with a view to obtaining decisive results the most easily, were not followed.

Experiments were made with cows by Voit at Munich,[1] by Wolff at Hohenheim,[2] and by G. Kühn at Möckern.[3] In those at Munich and at Hohenheim the amount of fat in the food, and that possibly derivable from the albumin consumed, very nearly corresponded with the amount of fat in the milk. In the experiments at Möckern, however, a small excess of milk-fat was produced. None of these experiments, therefore, afforded evidence of the formation of fat from the carbohydrates.

In experiments made by Kern and Wattenberg, at Göttingen,[4] with sheep of various ages, in ten cases the fat stored up fell short by 24 to 64 per cent. of that which could have been derived from the fatty matter and nitrogenous substance consumed. In one experiment, however, one animal was killed and the initial composition determined, and the other was fed for ten weeks, and the composition and digestibility of the food were determined. The results showed that 29·4 per cent. of the fat stored up must have been derived from other sources than the fat and the albumin of the food; and, even making all allowance for possible error, it was concluded that fat must have been derived from the carbohydrates consumed.

In other experiments at Göttingen, by T. Pfeiffer and Lehmann,[5] a similar result was obtained with a sheep fed with a considerable quantity of sugar.

In an experiment made by Wolff at Hohenheim,[6] a young pig was fed for 108 days with barley and maize-meal, with the addition of pure starch. The constituents digested were determined. Referring to the results, Wolff says that, having regard simply to the amounts of constituents consumed, and of increase produced, it is scarcely possible to suppose that the quantity of fat which must have been stored up could have been formed without the co-operation of the carbohydrates. He points out that fat equal to only 29 per cent. of the increase in live-weight could have been produced from the fat and the albumin of the

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[1] *Zeitschrift für Biologie*, 1869, p. 113.

[2] *Die Versuchsstationen, Hohenheim*, Berlin, 1870, p. 50; also M. Fleischer in *Virchow's Archiv für Patholog. Anat.*, Band 51, 1870.

[3] *Versuchsstationen*, 1869, Band 12, p. 451.

[4] *Journ. für Landw.* Jahrg. 26, p. 549.

[5] *Journ. für Landw.* 1885, Band 33, p. 337; also 1886, Band 34, p. 83.

[6] *Die rationelle Fütterung der landwirthschaftlichen Nutzthiere*, 5te Auff., 1888, p. 48.

food; and in this calculation he takes the whole of the albumin as available, without reckoning any to have been stored up. He adds that, according to the percentage of fat in increase in the Rothamsted experiment No. 1, there must have been 60 per cent. or more. According to our own calculation of Wolff's results, it seems probable that about 60 per cent. of the total fat in the increase must have been derived from carbohydrates. It is particularly to be observed that, in the case of this experiment, Wolff concluded that the formation of fat from the carbohydrates might be considered established, not only without any respiration apparatus, but even without any direct determination of fat in the animal.

Wolff quotes the results of experiments with pigs at Moscow, by Tschirwinsky, in 1880–1 and in 1881–2.[1] It was estimated that in the one case 61·6 per cent., and in the other 76·9 per cent. of the fat of the increase must have had its source in the carbohydrates of the food.

In an experiment made with a pig at Vienna by Meissl and Strohmer,[2] it was estimated that 82·2 per cent. of the stored-up fat must have been derived from the carbohydrates consumed.

At Proskau, Weiske and B. Schulze[3] made experiments with geese; and they concluded that in one case 13 per cent., and in the other 17·6 per cent. of the stored-up fat must have been derived from carbohydrates.

At Peterhof, near Riga, Chaniewski[4] experimented with geese; and from the results concluded that in one case 71·1 per cent., in another 78·6 per cent., and in a third 86·7 per cent. of the stored-up fat must have been derived from carbohydrates.

Wolff also quoted recent experiments by A. von Planta and Erlenmeyer, at Munich, with bees,[5] in which it was proved that wax had been formed from sugar.

Lastly, in 1880–1, Soxhlet made experiments with three pigs at the Agricultural Experiment Station at Munich.[6] The animals were five to six months old, they were fed for a preliminary period of 321 days with equal but limited amounts of barley-meal. No. 1 was then killed and analysed; No. 2 was fed for 75 days, and No. 3 for 82 days, with 4·4 lb. steamed rice per head per day for most of the time, but only three-fourths as much afterwards. Meat extract was also given for 50 days. Finally,

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[1] *Versuchsstationen*, 1883, Band 29, p. 317.

[2] *Ber. Acad. Wissens.*, Wien, 1883, Band 88, p. iii.

[3] & [4] E. Wolff, *Die rationelle Fütterung der landwirthschaftlichen Nutzthiere*, 5te Aufl. 1888, p. 50.

[5] *Bienenzeitung v. A. Schmidt*, 1878, p. 181.

[6] *Zeits. d. landw. Vereins in Bayern*, 1881, pp. 423–436.

Nos. 2 and 3 were killed and analysed. Calculation showed that the increase of No. 2 contained 14·19 per cent of nitrogenous substance, and 25·80 per cent. of fat; and that of No. 3, 7·25 per cent. of nitrogenous substance, and 57·23 per cent. of fat. That is, the increase of No. 3 contained only half as much nitrogenous substance, and more than twice as much fat, as that of No. 2; and even the higher proportion of fat (57·23) is low compared with that which would be obtained with animals of good breed, and rapidly fattened on appropriate food given *ad libitum*; whilst the composition of the increase of No. 2, both as to nitrogenous substance and fat, can hardly be called that of fattening increase at all. Still, calculation showed that, of the total fat in the increase of No. 2, 79·38, and in that of No. 3, 81·84 per cent., must have been derived from the carbohydrates of the food.

Notwithstanding the extraordinary difference in the composition of the increase of Soxhlet's pigs No. 2 and No. 3, after having been fed alike, he says that only our experiment No. 1 is admissible for calculation, because it is only in that case that the initial and final compositions were determined in parallel animals. He, in fact, accepts our least conclusive result, obtained with food abnormally rich in nitrogenous substance, and repudiates our most conclusive experiments with appropriate fattening food. Accordingly, he maintains that we had only shown the probability of the formation of fat from the carbohydrates, and that his own results, as above, were the first to prove it.

The discussion of the results of the nine experiments recorded in Table V. must have sufficed to show that in some of them a very large proportion of the fat of the increase must have been produced from the carbohydrates. The mode of calculation adopted showed, however, a maximum amount of the fat of the increase to have been possibly derivable from fatty matter in the food, a maximum amount of the nitrogenous substance of the food to be available for fat-formation, and a maximum amount producible from a given amount of nitrogenous substance; and hence a minimum amount necessarily derived from carbohydrates. But, as the results so calculated, and discussed with due reservation on these points, are those upon which we have for so many years maintained that the formation of fat from the carbohydrates has been proved, and as it is those results, and the conclusions drawn from them, that have instigated so much subsequent investigation leading to the confirmation of our views, it seemed desirable prominently to direct attention to the evidence as so brought out.

We have, however, as already said, long ago re-calculated many of our feeding experiments, making allowance, as far as practicable, for the probable amount of indigestible and necessarily effete matters of the foods. We have also, as referred to at pp. 28–31, arranged tables founded on our direct analytical results on the ten animals, showing the probable average percentage composition of the different descriptions of animal, each at eight gradationary points from the store to the very fat condition, and have applied the factors thus obtained, not only for the calculation of the composition of the increase in a number of cases of ordinary practice, and of direct experiment, but also for the re-calculation of some of the results to which Table V. relates. Accordingly, in the next Table (VI.) are given the results obtained in experiment No. 1, which were inconclusive according to the original mode of calculation; and also those obtained in experiments 4 and 5, which, even as originally calculated, could leave no doubt of very considerable formation of fat from the carbohydrates.

All these re-calculations are in the first place based on the assumption, since generally adopted by others, that 100 nitrogenous substance can at the most yield 51·4 of fat, instead of nearly 62, which would be the figure according to the original plan of calculation adopted in the construction of Table V.

Then, each experiment is now calculated three ways:—first, on the assumption that the whole of the fatty matter and the nitrogenous substance of the food were digested; secondly, supposing that only 90 per cent., and thirdly, that only 80 per cent. was digestible and available. Lastly, in the case of experiments 4 and 5, after very carefully considering the weights and character of the animals, and the duration of the fattening period, the initial and final composition have been taken, not as in Table V. the same as in experiment 1, but the initial at a composition three-eighths in advance from the store to the fat condition, and the final composition at a quarter in advance of fatness, compared with the fat pig of experiment 1. It is worthy of remark, that this carefully reconsidered independent mode of estimate gives almost precisely the same percentage of nitrogenous substance, and precisely the same of fat, in the *increase* in experiment 4, as in the former estimate, namely, now 5·4 instead of 5·3 per cent. of nitrogenous substance, and in both cases 79 per cent. of fat, the animals being all very fat. Again, the new mode of calculation gives for experiment 5, 6·4 per cent. of nitrogenous substance, and 72·3 per cent. of fat in the increase, instead of 6·5 and 71·2 per cent. as formerly adopted.

Let us first refer to the results of experiment 1, in which

TABLE VI.—*Sources of the Fat of the Animal Body. Abstract of Results of Experiments made at Rothamsted with Pigs. Results reckoning* 100 *Nitrogenous Substance in Food may yield* 51·4 *Fat.*

—		Experiment 1. Bean-meal, lentil-meal, and bran, each 1 part, barley-meal 3 parts			Experiment 4. Maize-meal, *ad lib.*			Experiment 5. Barley-meal, *ad lib.*		
Proportion of nit. sub. and fat digested		All	90 p.c.	80 p.c.	All	90 p.c.	80 p.c.	All	90 p.c.	80 p.c.
Albuminoid ratio[1]		3·8	3·8	3·8	7·3	7·3	7·3	6·3	6·3	6·3
FOR 100 INCREASE IN LIVE-WEIGHT.										
Nitrogenous substance	In food	100·0	90·0	80·0	57·0	51·3	45·6	64·0	57·6	51·2
	In increase	7·8	7·8	7·8	5·4	5·4	5·4	6·4	6·4	6·4
	Available for fat formation	92·2	82·2	72·2	51·6	45·9	40·2	57·6	51·2	44·8
Fat	In increase	63·1	63·1	63·1	79·0	79·0	79·0	72·3	72·3	72·3
	In food	15·6	14·0	12·5	26·3	23·7	21·0	12·4	11·2	9·9
	Newly formed	47·5	49·1	50·6	52·7	55·3	58·0	59·9	61·1	62·4
	Derivable from nit. sub.	47·4	42·3	37·1	26·5	23·6	20·7	29·6	26·3	23·0
	From carbohydrates	0·1	6·8	13·5	26·2	31·7	37·3	30·3	34·8	39·4
FOR 100 TOTAL FAT IN INCREASE.										
Fat	From fat in food	24·7	22·2	19·8	33·3	30·0	26·6	17·2	15·5	13·7
	Derivable from nit. sub.	75·1	67·0	58·8	33·5	29·9	26·2	40·9	36·4	31·8
	From carbohydrates	0·2	10·8	21·4	33·2	40·1	47·2	41·9	48·1	54·5
FOR 100 NEWLY-FORMED FAT.										
Fat	Derivable from nit. sub.	99·8	86·1	73·3	50·3	42·7	35·7	49·4	43·0	36·9
	From carbohydrates	0·2	13·9	26·7	49·7	57·3	64·3	50·6	57·0	63·1

[1] In the calculation of these ratios, the nitrogen is, as in Table V., multiplied by 6·3 to represent total nitrogenous substance; and for column 1 of each experiment no deduction is made. For all three columns of each experiment, the crude fat is multiplied by 2·4 to bring it into its equivalent of starch. For column 1 the amount of non-nitrogenous substance *not fat*, is taken without deduction; but for columns 2 and 3, as in the case of the nitrogenous substance and the fat, only 90 or 80 per cent. respectively, of the total is assumed to be digested.

parallel animals were analysed, but in which, as has been pointed out, the food was much more highly nitrogenous than is appropriate in the fattening food of the pig. Those given in column 1, in which it is assumed that the whole, both of the nitrogenous substance and of the fat of the food, was digestible and available, show that, when we now reckon only 51·4 instead of about 62 parts of fat to be derivable from 100 nitrogenous substance, even this experiment indicates that the fat in the food, and that derivable from the nitrogenous substance consumed, were scarcely sufficient to cover the whole of the fat of the increase. Obviously, too, if it be assumed, according to the more recent estimate, that only about 42 parts of fat can be derived from 100 of albuminoid substance, there would then, even in this experiment, with such abnormally high nitrogenous food, be a considerable formation of fat from carbohydrates.

Turning to the results in the second column, which are calculated on the assumption that only 90 per cent. of the nitrogenous substance, and 90 per cent. of the fatty matter, of the food would be digested, it is seen that—for 100 increase in live-weight 6·8 parts, for 100 total fat in the increase 10·8 parts, or for 100 newly-formed fat 13·9 parts, must have been derived from carbohydrates.

Lastly, in regard to experiment 1, reckoning only 80 per cent. of the nitrogenous substance and fat of the food to have been digested and available, the result would be that 13·5 of the 63·1 parts of fat in 100 of increase must have had some other source than fat and nitrogenous substance of the food; or reckoned for 100 total fat in the increase, 21·4 parts, or for 100 newly-formed fat 26·7 parts, must have been derived from carbohydrates.

In regard to the alternative assumptions that only 90 or only 80 per cent. of the nitrogenous and fatty matters of the food were digested, it may be stated that in Wolff's Tables, published in *Mentzel und v. Lengerke's landwirthschaftlicher Kalender* for 1890, he reckons 88 per cent. of the nitrogenous substance of beans, 89·9 per cent. of that of lentils, 77·9 per cent. of that of bran, 79·2 per cent. of that of maize, and 77 per cent. of that of barley, to be on the average digested; and of the fatty matter of these foods, he reckons 87·5 per cent. of that of beans, 84·6 per cent. of that of lentils, 70·6 per cent. of that of bran, 85·1 per cent. of that of maize, but the whole, or 100 per cent., of that of barley, to be digestible. So far, therefore, as experiment 1 is concerned, according to Wolff's factors the truth would lie somewhere between the results supposing 90 and those supposing 80 per cent. digested.

Even in this experiment, then (No. 1), there is clear evidence of the formation of fat from the carbohydrates, when deduction is made for indigestible nitrogenous and fatty matters consumed, and when it is reckoned that only 51·4 parts of fat may be produced from 100 albuminoid substance. Obviously, if only 42 parts of fat, as assumed by some, can be formed from 100 albumin, the evidence is clearer still.

Turning now to experiment 4, in which the food was maize-meal alone, given *ad libitum*, and the relation of non-nitrogenous to 1 of nitrogenous substance was much higher than in experiment 1, and much more appropriate for the rapid fattening of the pig, the results are much more decisive. They were, indeed, quite conclusive as originally calculated, without the emendations now adopted.

The results, even as given in the first of the three columns, in the calculation of which it is assumed that the whole of the nitrogenous substance and fat of the food were digested and available, show that—for 100 increase in live-weight 26·2 parts of fat, for 100 total fat in increase 33·2, and for 100 newly-formed fat 49·7 parts, must have been derived from carbohydrates.

Reckoning, as in the second column, that 90 per cent. of the nitrogenous substance and fatty matter consumed were digestible and available, the calculations show that—for 100 increase in live-weight 31·7 parts of fat, for 100 total fat in increase 40·1 parts, and for 100 newly-formed fat 57·3 parts, would be derived from carbohydrates. Or, reckoning as in the third column, that only 80 per cent. of the nitrogenous substance and fat of the food were digested and available, the results show that—for 100 increase in live-weight 37·3 parts of fat, for 100 total fat in the increase 47·2 parts, and for 100 newly-formed fat 64·3 parts, or nearly two-thirds, of the total produced fat, would have its source in the carbohydrates.

It may be observed that, in the case of this experiment with maize, the results given in the third column would very nearly accord with those which would be obtained if Wolff's average percentages of digestible constituents had been adopted.

Let us now refer to the results of experiment 5, in which the food was barley-meal alone, given *ad libitum*, and the albuminoid ratio was nearly that recognised as most suitable for the rapid fattening of the pig.

The first of the three columns, calculated on the assumption that the whole of the nitrogenous substance and fat consumed were digested, shows that under such conditions there would be —for 100 increase in live-weight 30·3 parts of fat, for 100 total fat in increase 41·9 parts, and for 100 newly-formed fat 50·6

parts, or about half, that must have been derived from other constituents than the fatty matter and nitrogenous substance of the food.

The results in the second column, calculated on the assumption that 90 per cent. of the fatty matter and nitrogenous substance were digested, show that—in 100 increase in live-weight 34·8 parts of fat, in 100 of total fat in increase 48·1 parts, and of 100 newly-formed fat 57·0 parts, must have been formed from carbohydrates.

Lastly, the results in the third column, reckoning only 80 per cent. of the nitrogenous substance and fat to be digested, show that on this supposition—of 100 increase in live-weight 39·4 parts of fat, of 100 total fat in increase 54·5 parts, or of 100 newly-formed fat 63·1 parts, or again nearly two-thirds, must have been derived from carbohydrates.

So much for the evidence of results relating to pigs, in their bearing on the question of the sources of their fat, when fed on their appropriate fattening food. It is cumulative and decisive, that at any rate a large proportion of the stored-up fat must have its source in other constituents than the fat and nitrogenous substance of the food, in other words—*in the carbohydrates.*

The Experiments at Rothamsted with Sheep.

It has been pointed out that, compared with pigs, there is with ruminants a much smaller amount of increase obtained, in proportion both to their weight within a given time, and to a given amount of food passed through the body; that there is also a much larger amount of necessarily effete matter in their food; and that, therefore, the result of calculations of feeding experiments with them in regard to the question of the sources in the food of the fat stored up in the body is less conclusive. It will, nevertheless, be of interest to adduce some direct experimental evidence on the point.

Some time after the discussion at Hamburg, in 1876, two sets of experiments made at Rothamsted with sheep, in which the concentrated foods were barley or malt, and in which, therefore, the amount and proportion of nitrogenous substance consumed were low, were selected for calculation.

The first series comprised five pens, with four or five sheep in each. The experiments had been made in the spring of 1849, and extended over a final fattening period of ten weeks. In each pen barley or malt was given in fixed quantity per head per day, and in each pen also mangel was given in addition, *ad libitum.*

The second series also comprised five pens, but with twelve sheep in each. The experiments were made in the winter of 1863–4, and they extended over a final fattening period of twenty weeks. The animals were at an earlier stage of progress at the commencement than, and not quite so mature at the conclusion as, those of the other series. In each pen barley or malt was given in fixed quantity per head, in each clover chaff also in fixed quantity, and in each roots were given *ad libitum*; swedish turnips during the first sixteen weeks, and a mixture of one-fourth swedes and three-fourths mangel during the last four weeks of the twenty.

The results of these two series of experiments with sheep, calculated to show their bearing on the question of the sources of the fat stored up by the animals, are given in Table VII.

It will be seen that the form of the table is, so far as the facts will allow, the same as has been adopted in the case of the various experiments with pigs. A general description of the food of each series is given over the columns relating to the series, and at the head of each separate column is given a description of the limited food supplied to each pen.

The results are calculated for 100 increase in live-weight. Referring to the upper division of the table, there are first shown—the amounts of nitrogenous substance (digestible) in the fixed food, the amounts in the increase, and the difference =the amounts available for fat-formation. Next are given—the amounts of fat in the increase, in the total food (digestible), and the difference=the newly-formed fat; the amounts derivable from the available nitrogenous substance in the fixed food, and the difference=the amount required to be produced from other sources. Then, in the lower division of the table are given, for each pen, the amounts of fat derivable from the nitrogenous substance of the roots, on the alternative assumptions that 50, 60, 70, 80, 90 per cent., or the whole, of that which they contain, will be digestible and available for fat-formation.

It should be further explained, that 80 per cent. of the nitrogenous substance of barley or of malt is reckoned as digestible and available for the purposes of the system. Wolff's estimates were, in 1874, 80 per cent., in 1888, 77·3 per cent., and in 1890, 77 per cent. In malt-dust, 80 per cent. is assumed to be digestible, against Wolff's estimate of 80 per cent. in 1874, and 82 per cent. in 1888 and 1890. In clover-chaff two-thirds, or 66·7 per cent., of the nitrogenous substance is reckoned as digestible, against a range in Wolff's Tables, according to quality, from 51·4 to 69·9 per cent. In the cases of swedish turnips and mangel, Wolff assumes the whole of the nitro-

TABLE VII.—*Sources of the Fat of the Animal Body. Experiments at Rothamsted with Sheep. Assumed that* 100 *digestible Nitrogenous Substance in Food may yield* 51·4 *Fat.*

	Fixed food—barley or malt; mangel *ad lib.*					Fixed food—barley or malt, and clover-chaff; roots (swedes and mangel) *ad lib.*				
	1	2	3	4	5	1	2	3	4	5
	Barley	Malt and malt-dust	Barley steeped	Malt and malt-dust steeped	Malt and malt-dust, extra quantity	Barley and clover-chaff	Malt and clover-chaff	Barley and clover-chaff	Malt and clover-chaff	Barley (⅔), malt (⅓), and clover-chaff
PER 100 INCREASE IN LIVE-WEIGHT.										
Nitrogenous substance: In fixed food (digestible)	25·0	23·3	19·9	25·0	27·9	52·4	51·1	55·8	55·9	58·6
Nitrogenous substance: In increase	6·5	6·5	6·5	6·5	6·5	7·5	7·5	7·5	7·5	7·5
Nitrogenous substance: Available for fat-formation	18·5	16·8	13·4	18·5	21·4	44·9	43·6	48·3	48·4	51·1
Fat: In increase	74·0	74·0	74·0	74·0	74·0	69·0	69·0	69·0	69·0	69·0
Fat: In total food (digestible)	10·3	8·8	9·6	10·3	10·2	13·1	12·9	13·0	13·3	13·8
Fat: Newly-formed	63·7	65·2	64·4	63·7	63·8	55·9	56·1	56·0	55·7	55·2
Fat: Derivable from nit. sub.	9·5	8·6	6·9	9·5	11·0	23·1	22·4	24·8	24·9	26·3
Fat: From other sources	54·2	56·6	57·5	54·2	52·8	32·8	33·7	31·2	30·8	28·9
FAT DERIVABLE FROM THE NITROGENOUS SUBSTANCE OF THE ROOTS, ACCORDING TO THE PERCENTAGE OF IT CAPABLE OF FAT-FORMATION.										
Fat from nit. sub. of roots: If 50 per cent. capable of fat-formation	22·2	20·8	24·4	26·6	23·3	14·1	14·0	14·0	14·2	14·8
Fat from nit. sub. of roots: If 60 „ „	26·6	25·0	29·3	31·9	28·0	16·9	16·8	16·9	17·0	17·8
Fat from nit. sub. of roots: If 70 „ „	31·1	29·1	34·2	37·2	32·6	19·7	19·6	19·7	19·9	20·7
Fat from nit. sub. of roots: If 80 „ „	35·5	33·3	39·0	42·6	37·3	22·6	22·4	22·5	22·7	23·7
Fat from nit. sub. of roots: If 90 „ „	40·0	37·4	43·9	47·9	41·9	25·4	25·2	25·3	25·6	26·6
Fat from nit. sub. of roots: If 100 „ „	44·4	41·6	48·8	53·2	46·6	28·2	28·0	28·1	28·4	29·6

genous substance to be digestible and available, drawing no distinction in this respect between the amounts existing as albuminoids, as amides, or in other forms. To this point we shall have to refer in more detail presently.

Then as to the fat of the foods: the percentage of it reckoned as digestible is that given in Wolff's Tables of 1874. In the case of barley, he then reckoned only 68 per cent. of the total to be digestible; but more recently he has supposed the whole of it to be so. For clover-chaff his figures are the same at all three periods, as are also those for mangel.

Let us now turn to the calculated results as given in the table, and first to those relating to the first series of five pens, in which the fixed food was either barley or malt, and the *ad libitum* food consisted of mangel only. As already said, the period of experiment comprised only the last ten weeks of fattening. Hence it commenced at a somewhat advanced stage of progress, and the animals were, at the conclusion, probably fully as fat as, if not fatter than, the sheep which had been analysed as "*fat.*" Taking into account the weight and condition of the animals at the beginning and at the end, and the percentages of carcass and of inside fat in the live-weight, it is calculated that the increase over this short finishing period would contain 74 per cent. of fat, and only 6·5 per cent. of nitrogenous substance.

On these assumptions the figures show that, after deducting the estimated amount of nitrogenous substance in 100 of increase from the amount supplied in the fixed food, there remained in the different cases—18·5, 16·8, 13·4, 18·5, and 21·4 parts of nitrogenous substance available from the fixed foods for the formation of fat.

Next as to the fat:—deducting the amount of the digestible fat supplied in the total food from the fat in the increase, there remain in the respective cases—63·7, 65·2, 64·4, 63·7, and 63·8 parts, which must have been newly-formed. There is next shown the amount of this which may have been derived from the available nitrogenous substance of the fixed food; and it is seen that there remain—54·2, 56·6, 57·5, 54·2, and 52·8 parts, out of the total of 74 in the 100 of increase, that must have been derived from other sources; in fact, either from the nitrogenous substance of the roots, or from the carbohydrates of the fixed food and the roots.

The next question is, whether the nitrogenous substance of the roots could have yielded the amounts of fat indicated to have been produced from other sources than the fat of the total food, and that derivable from the available nitrogenous

substance of the fixed foods. Comparing the figures in the bottom line of the lower division of the table with those in the bottom line of the upper division, it is seen that, even on the impossible assumption that the whole of the nitrogen of the mangel existed in compounds of the same fat-forming value as the albuminoids, in neither of the five cases would the amount so available completely supply the amount required.

The amount of true albuminoid nitrogen varies very much in different descriptions of roots, and in the same description according to season, maturity, &c. Thus, at Rothamsted we have found it in mangel as low as 20·5 per cent. of the total nitrogen under unfavourable conditions of growth and ripening, and as high as 44·2 under favourable conditions. We generally assume in calculation that 40 per cent. of the nitrogen of mangel will, on the average, exist as albuminoids; and Wolff's average figure, as given in 1888, is 36·1 per cent. The amount existing as amides will probably, in most cases, vary from 40 to 50 per cent. or more, whilst there is frequently a considerable quantity as nitrates, the more the less ripe the roots; and we have sometimes found the amount to be more than 10 per cent. of the total nitrogen of the roots.

It is clear, therefore, that even supposing as little as 50 per cent. of the nitrogen of the roots to be available for, and capable of, fat-formation, as assumed in the top line of the lower division of the table, that amount would generally include other than albuminoid compounds. Nevertheless, Wolff in his tables assumes the whole of the nitrogen of roots to be digestible and available for the purposes of the system, since it has been shown that amides are transformed in the body and yield urea; leaving, therefore, by-products of transformation available for expenditure in respiration, and so protecting the true albuminoids, or the carbohydrates.

There is, however, so far as we are aware, no direct experimental evidence yet at command indicating that the by-products of the transformation of amides may directly contribute to the formation of fat. Results of independent experimenters have, however, shown that the heat of combustion of asparagine for example, is only about, or little more than, half that of albumin; and supposing that the amides do directly contribute to the formation of fat, it may safely be concluded that a given quantity of amide would yield very much less fat than an equal quantity of albuminoid. As bearing upon this point, it is to be borne in mind that, on the average, the amide bodies most frequently occurring in food-stuffs have a higher percentage of nitrogen than the albuminoids. Wolff estimates that whilst the nitrogen of food should be $\times 6{\cdot}25$ to represent albuminoids,

5·5 would, on the average, be a more appropriate factor for calculating the amount of amide from that of the nitrogen. Further, he admits that so far as the nitrogen in potatoes, roots, and other food-stuffs exists as amides, the nutritive value of the food is reduced; nevertheless, as has been said, in his tables he assumes the whole of the nitrogenous substance of roots to be digestible, and of equal value with the albuminoids.

Then again, as generally more or less of the nitrogen in roots will exist as nitrates, it will so far not only have no food value, but it may be positively injurious. It may be added that, other things being equal, the higher the percentage of nitrogen in roots, the lower as a rule will be the proportion of it as albuminoids, and the higher that as amides and as nitrates, &c. Further, in direct experiments at Rothamsted with sheep feeding on roots alone, it was found that whilst the animals even gained in weight on ripe roots, low in nitrogen, they actually lost on roots that were less ripe, high in nitrogen, and doubtless containing a larger proportion of their nitrogen as non-albuminoid compounds.

From these various considerations it is obvious that by no means the whole of the nitrogen of the mangel can be estimated as having existed in compounds which could, in their transformation, yield the amount of fat possibly derivable from true albuminoids. However, with the great variation in the proportion of albuminoids and amides in roots, and the absence of exact knowledge as to the probable value, if any, direct or indirect, of amides for fat-formation, it is impossible to form any certain estimate as to which of the percentages given alternatively in the lower division of the table most probably represents the amount of fat producible from the nitrogenous substance of the mangel given *ad libitum* in each of the five pens of the first series of experiments with sheep. It is, however, quite safe to conclude that very much less than the whole would be so available; and if we were to assume that of the nitrogenous constituents of the roots only the albuminoids would be available for fat-formation, the figures given in the top line of the lower division of the table, according to which it is reckoned that only 50 per cent. of the total nitrogenous compounds of the roots would be capable of fat-formation, would in each case represent less than half the amount required.

It is quite clear that at any rate a large proportion of the increase estimated to be necessarily derived from other sources than the fat of the total food, and the nitrogenous substance of the fixed food, must have been derived from other sources than the nitrogenous substance of the roots; in other words, it must

have had its source in the carbohydrates of the fixed food or of the roots.

Let us now examine the evidence of the results of the second series of experiments, on somewhat similar lines.

As in series 1, a fixed quantity of barley or malt was given in each pen, but now a fixed quantity of clover-chaff also. This introduction of clover-chaff into the fixed food brings us again face to face with the difficulty as to the estimation of the food-value of the amides. As already said, the calculation of the amounts of the nitrogenous substance in the clover-chaff which will be available are made on the assumption that 66·7 per cent. of the total nitrogen will be digestible, and so available; and this figure agrees fairly with Wolff's estimates. But this amount includes amides as well as albuminoids. In Wolff's most recent tables he estimates that the proportion of the nitrogen of clover-hay existing in non-albuminoid compounds may range from 13·9 to 29·9 per cent. of the whole, and probably be on the average about 19 per cent. What proportion, however, of the two-thirds of the total nitrogenous substance of clover-hay, which is estimated to be digestible, will probably be non-albuminoid there is no evidence to show. In these circumstances we have, in the calculations, assumed the whole of the digestible nitrogenous substance of clover-hay to have the food-value of albuminoids. The figures will, therefore, doubtless overstate the amount of the nitrogenous substance consumed in the fixed foods which is really available for nitrogenous increase and for fat-formation.

Taking the figures as they stand, it is seen that, after deducting the amount of nitrogenous substance estimated to be stored up in 100 of increase from the amount supplied in the fixed food, there remain in the several experiments—44·9, 43·6, 48·3, 48·4, and 51·1 parts, possibly available for fat-formation.

Then, deducting the amount of digestible fat in the total food from the fat estimated to be stored up in the increase, there remain—55·9, 56·1, 56·0, 55·7, and 55·2 parts, which must have been newly-formed. Deducting from these amounts those producible from the available nitrogenous substance of the fixed foods, there remain—32·8, 33·7, 31·2, 30·8, and 28·9 parts, to be formed from other sources. Comparing with these amounts those derivable from the nitrogenous substance of the roots, assuming, as shown in the bottom line of the table, that the whole of it would have the same value for fat-formation as true albuminoids, it is seen that in four out of the five cases the fat so assumed to be formed would be less than that required.

In these experiments the roots consisted chiefly of swedish

turnips, and in only small proportion of mangel. The evidence at command leads to the conclusion that, in swedish turnips, a larger proportion of the total nitrogen exists as albuminoids, and a less proportion as nitrates, than in the more succulent mangel. We have found the proportion of the total nitrogen of swedish turnips existing as albuminoids as low as 32·9, and as high as 55·8; and for the purposes of calculation we assume that, on the average, 45 per cent. will be in that form. As large or a larger amount will, however, exist as amides than in mangel.

It is evident, therefore, that even if we assume 50 per cent. of the total nitrogenous substance of the roots consumed in this second series of experiments to have been of value for fat-formation, some amide will be included. But, even on the assumption that 50 per cent. had the value of albuminoids for fat-formation, less than half the amount of fat required would be derivable from the nitrogenous substance of the roots. Assuming, however, that the amides of the roots would, as such, have a certain, though not an equal, value with the albuminoids for fat-formation, or that, as protectors of other constituents, they may contribute indirectly to such formation, there would still remain a considerable amount of the produced fat to be derived from other sources—that is, from carbohydrates.

Upon the whole, then, although the evidence of fat-formation from the carbohydrates of the food is admittedly less direct in the case of sheep than in that of pigs, yet, when the foregoing results are carefully considered with due regard to the facts which have been discussed, no doubt can be entertained that there was a considerable formation of fat from carbohydrates in both of the series of experiments with sheep. And when it is borne in mind that neither of these series of experiments was arranged for the purpose of elucidating this particular question, it must be admitted that the results are more definite and conclusive than might have been anticipated. Nor can there be any doubt that if experiments were made with oxen under suitable conditions, they would yield equally conclusive evidence on the point. Indeed, as anticipated by Henneberg in the observations he made at Hamburg in 1876, we may consider that the carbohydrates are re-instated in their position in the formation of the fat of ruminants as well as in that of pigs.

Summary on the Sources of the Fat of the Animals of the Farm.

It was in 1865, that is, nearly thirty years ago, that Voit first called in question the then very generally accepted opinions on the subject; and as his evidence, derived from

experiments with the omnivorous dog, accumulated, he more and more urged that his conclusions were equally applicable to herbivora. His views on the point came to be very generally adopted by agricultural chemists in Germany, and, in 1874, Professor Emil von Wolff adopted them, but with some reservation so far as pigs are concerned, in his text-book entitled *Die rationelle Fütterung der landwirthschaftlichen Nutzthiere; auf Grundlage der neueren thierphysiologischen Forschungen.*

It has been already stated that, in the discussion at Hamburg in 1876, Wolff more clearly admitted that pigs might behave exceptionally in the matter; whilst Henneberg assumed that ruminants also would prove to be exceptions to the application of Voit's views.

Since that date a number of experiments have been made in Germany and elsewhere, both with pigs and with ruminants, to elucidate the point; and when the conditions of the experiments were suited to the object, the results contributed to the re-establishment of the conclusion that the carbohydrates play a very direct and important part in the fat-formation of the animals of the farm.

Further, in the edition of Wolff's work published in 1888 he almost unreservedly admits the *rôle* of the carbohydrates in the formation of at least a great part of the fat not only of pigs but of ruminants. Indeed, some years previously, Voit himself had made substantial concessions on the point.[1]

It happens, however, that about 1880 Dr. Armsby, now the Director of the Agricultural Experiment Station at the Pennsylvania State College, published a work which has since passed through several editions, entitled *Manual of Cattle-Feeding; a Treatise on the Laws of Animal Nutrition and the Chemistry of Feeding-Stuffs in their application to the Feeding of Farm-Animals*, which was a very good digest, chiefly of the work done in Germany, on the subject.

So far as the question of the sources of fat is concerned, it gives numerous tabular illustrations from Voit's work; and it follows almost exclusively the views of Voit and of Wolff at that time. He, however, quotes results, obtained both with pigs and with other animals, which, he admitted, indicate, according to the figures, the formation of fat from the carbohydrates. But he considered that the data at command were not sufficient to solve the problem; and, with Wolff, assumed that the question could not be satisfactorily settled without experiments in a respiration apparatus. He also considered

[1] Hermann's *Handbuch d. Physiologie*, Band 6, Theil 1, von C. v. Voit, Leipzig, 1881.

that estimates founded on the composition of the increase of fattening animals as determined at Rothamsted, are uncertain. He, nevertheless, concluded that the carbohydrates may serve as a source of fat to swine, and under some circumstances to other animals also.

It happens that Dr. Armsby's book, founded to a great extent on Wolff's earlier editions, was the only work of the kind in the English language; and hence many of the rising generation of agricultural chemists, both in this country and in America, adopted the view that the albuminoids are the main, if not the exclusive, source of the fat of our farm stock, and of the butter of cows' milk.

Under these circumstances it seemed desirable to consider in some detail, both the experimental evidence bearing upon the question, and the discussions which have taken place in regard to it during the last quarter of a century or more. It must be admitted, that the importance of the carbohydrates as a direct source of much, if not of the whole, of the fat stored up in the animals which the farmer feeds has been clearly re-established. We have reason to believe that Dr. Armsby himself adopts the change of view; though it will probably be some time before the truth is thoroughly recognised by the younger agricultural chemists.

It was maintained by Voit and others, that to establish the formation of fat from the carbohydrates it must be experimentally shown that the fat deposited was in excess of that supplied by the food, *plus* that which could be derived from transformed albumin. But it is obvious that the mere fact that the food contained enough nitrogenous substance for the formation of all the fat that had been produced would of itself be no proof that that substance had been its source. It has been seen, however, that Voit's requirement was amply fulfilled in the Rothamsted experiments, both with pigs and with sheep; and hence it must be admitted to be proved, that at any rate some of the stored-up fat must have had another source, which could only be the carbohydrates.

In winding up the discussion, perhaps we cannot do better than reiterate the conclusions given in our paper on the subject in 1866, namely:—

1. That certainly a large proportion of the fat of the herbivora fattened for human food must be derived from other substances than fatty matter in the food.

2. That when fattening animals are fed upon their most appropriate food, much of their stored-up fat must be produced from the carbohydrates it supplies.

3. That nitrogenous substance may also serve as a source of fat, more especially when it is in excess, and the supply of available non-nitrogenous constituents is relatively defective.

Food and Milk Production.

Milk-production, and the dairy industry, are of such great and growing importance, and their various branches involve so many points of interest, that much time and space would be required to adequately discuss them. But when considering what are the animal products of value derived from the consumption of food on the farm, it would obviously be inappropriate not to refer, however briefly, to the question of milk-production in some of its aspects.

Attention must, however, be confined almost exclusively to the great difference in the demands made on the food—on the one hand for the production of meat, that is of animal increase, and on the other for the production of milk. But not only do cows of different breeds yield different quantities of milk, and milk of characteristically different composition, but individual animals of the same breed have very different milk-yielding capacity; and whatever the capacity of a cow may be, she has a maximum yield at one period of her lactation, which is followed by a gradual decline. Hence, in comparing the amounts of constituents stored up in the fattening increase of an ox with the amounts of the same constituents removed in the milk of a cow, we must assume a wide range of difference in the yield of milk.

Accordingly, Table VIII. shows—the amounts of nitrogenous substance, of fat, of non-nitrogenous substance not fat, of mineral matter, and of total solid matter, carried off in the weekly yield of milk of a cow, on the alternative assumptions of a produce of— 4, 6, 8, 10, 12, 14, 16, 18, or 20 quarts per head per day; and, for comparison, there is given at the bottom of the table the amounts of nitrogenous substance, of fat, of mineral matter, and of total solid matter, in the weekly increase in live-weight of a fattening ox, of an average weight of 1,000 lb. —first on the assumption of a weekly increase of 10 lb., and secondly of 15 lb.

The estimates of the amounts of constituents in the milk are based on the assumption that it will contain—12·5 per cent. of total solids, consisting of 3·65 albuminoids, 3·50 butter-fat, 4·60 sugar, and 0·75 of mineral matter. The estimates of the constituents in the fattening increase of oxen are founded on

the determinations at Rothamsted of such increase as already described.

TABLE VIII.—*Comparison of the Constituents of Food carried off in Milk, and in the Fattening Increase of Oxen.*

[1 Gallon = 10·33 lb.]	Nitrogenous substance	Fat	Non-nitrogenous substance not fat (sugar)	Mineral matter	Total solid matter
IN MILK PER WEEK.					
If:—	lb.	lb.	lb.	lb.	lb.
4 quarts per head per day	2·64	2·53	3·33	0·54	9·04
6 " " "	3·96	3·80	4·99	0·81	13·56
8 " " "	5·28	5·06	6·66	1·08	18·08
10 " " "	6·60	6·33	8·32	1·35	22·60
12 " " "	7·92	7·59	9·99	1·62	27·12
14 " " "	9·24	8·86	11·65	1·89	31·64
16 " " "	10·56	10·12	13·32	2·16	36·16
18 " " "	11·88	11·39	14·98	2·43	40·68
20 " " "	13·20	12·65	16·65	2·70	45·20
IN INCREASE IN LIVE-WEIGHT PER WEEK.—OXEN.					
If 10 lb. increase . .	0·75	6·35	—	0·15	7·25
If 15 lb. increase . .	1·13	9·53	—	0·22	10·88

Referring to the very wide range of yield of milk per head per day which the figures in the table assume, it may be remarked that it is by no means impossible that the same animal might yield the largest amount—namely, 20 quarts, or 5 gallons, per day near the beginning, and only 4 quarts, or 1 gallon, or even less, towards the end of her period of lactation. At the same time, an entire herd of, say, Shorthorns or Ayrshires, of fairly average quality, well fed, and including animals at various periods of lactation, should not yield an average of less than 8 quarts, or 2 gallons, and would seldom exceed 10 quarts, or 2½ gallons, per head per day, the year round.

For the sake of illustration, then, let us assume an average yield of milk of 10 quarts, equal 2½ gallons, or between 25 and 26 lb. per head per day; and let us compare the amount of constituents in the weekly yield at this rate, with that in the weekly increase of the fattening ox at the higher rate assumed in the table—namely, 15 lb. per 1,000 live-weight, or 1·5 per cent. per week.

Thus, whilst of the nitrogenous substance of the food the amount stored up in the fattening increase of an ox will be only 1·13 lb., the amount carried off as such in the milk would

be 6·6 lb., or nearly six times as much. Of mineral matter, again, whilst the fattening increase would only require about 0·22 lb., the milk would carry off 1·35 lb., or again about six times as much. Of fat, however, whilst the fattening increase would contain 9·53 lb., the milk would contain only 6·33 lb., or only about two-thirds as much. On the other hand, whilst the fattening increase contains no other non-nitrogenous substance than fat, the milk would carry off 8·32 lb. in the form of milk-sugar. It may be observed, that this amount of milk-sugar reckoned as fat would correspond approximately to the difference between the fat in the milk and that in the fattening increase.

From the foregoing comparison, it is evident that the drain upon the food is very much greater for the production of milk than for that of meat. This is especially the case in the important item of nitrogenous substance; and if, as is frequently assumed, the butter-fat of the milk is, at any rate, largely derived from the nitrogenous substance of the food, so far as it is so, at least about two parts of such substance would be required to produce one of fat. On such an assumption, therefore, the drain upon the nitrogenous substance of the food would be very much greater than that indicated in the table as existing as nitrogenous substance in the milk. To this point further reference will be made presently.

We will next call attention to the amounts of food, and of certain of its constituents, consumed for the production of a given amount of milk. This point is illustrated in Table IX., which shows the constituents consumed per 1,000 lb. live-weight per day, in the case of the Rothamsted herd, then of 30 cows, in the spring of 1884.

On the left hand are shown the actual amounts of the different foods consumed per 1,000 lb. live-weight per day; and in the respective columns are recorded—first the amounts of total dry substance which the foods contained, and then the amounts of digestible nitrogenous, digestible non-nitrogenous (reckoned as starch), and digestible total organic substance, which the different foods would supply; these being calculated according to our own estimates of the percentage composition of the foods, and to Wolff's estimates of the proportion of the several constituents which would be digestible.

The first column shows that the amount of total dry substance of food actually consumed by the herd, per 1,000 lb. live-weight per day, was scarcely 20 lb., whilst Wolff's [1] estimated

[1] *Landw. Fütterungslehre*, 5te Aufl., 1888, p. 249.

requirement, as stated at the foot of the table, is 24 lb. But his ration would doubtless consist in larger proportion of hay and straw-chaff, containing a larger proportion of indigestible and effete woody-fibre. The figures show, indeed, that the Rothamsted ration supplied, though nearly the same, even a somewhat less amount of total digestible constituents than Wolff's.

TABLE IX.—*Constituents consumed per* 1,000 *lb. Live-Weight per Day, for Sustenance and for Milk Production. The Rothamsted Herd of* 30 *Cows, Spring* 1884.

—	Total dry substance	Digestible		
		Nitrogenous substance	Non-nitrogenous substance (as starch)	Total nit. and non-nit. substance
	lb.	lb.	lb.	lb.
3·1 lb. Cotton cake	2·76	1·07	1·50	2·57
2·7 lb. Bran	2·33	0·33	1·09	1·42
2·8 lb. Hay-chaff	2·34	0·15	1·18	1·33
5·6 lb. Oat-straw-chaff	4·64	0·08	2·21	2·29
62·8 lb. Mangel	7·85	1·01	5·73	6·74
Total	19·92	2·64[1]	11·71[1]	14·35
Required for sustenance	—	0·57	7·40	7·97
Available for milk	—	2·07	4·31	6·38
In 23·3 lb. milk	—	0·85	3·02	3·87
Excess in food	—	1·22	1·29	2·51
PER 1,000 lb. LIVE-WEIGHT.				
Wolff	lb. 24	lb. 2·5	lb. 12·5[2]	lb. 15·4

[1] Albuminoid ratio 1–4·4. [2] Exclusive of 0·4 fat; albuminoid ratio 1–5·4.

Of digestible nitrogenous substance, the food supplied 2·64 lb. per day, whilst the amount estimated to be required for sustenance merely is 0·57 lb.; leaving, therefore, 2·07 lb. available for milk-production. The 23·3 lb. of milk yielded per 1,000 lb. live-weight per day would, however, contain only 0·85 lb.; and there would thus remain an apparent excess of 1·22 lb. of digestible nitrogenous substance in the food supplied. But, against the amount of 2·64 lb. actually consumed, Wolff's estimate of the amount required for sustenance and for milk-production is 2·5 lb., or but little less than the amount actually consumed at Rothamsted. On the assumption that the expenditure of nitrogenous sub-

stance in the production of milk is only in the formation of the nitrogenous substances of the milk, there would appear to have been a considerable excess given in the food.

But Wolff's estimate assumes no excess of supply, and that the whole is utilised; the fact being that he supposes the butter-fat of the milk to have been derived largely, if not wholly, from the albuminoids of the food.

It has been shown, that although it is possible that some of the fat of a fattening animal may be produced from the albuminoids of the food, certainly the greater part of it, if not the whole, is derived from the carbohydrates. But the physiological conditions of the production of milk are so different from those for the production of fattening increase, that it is not admissible to judge of the sources of the fat of the one from what may be established in regard to the other. It has been assumed, however, by those who maintain that the fat of the fattening animal is formed from albuminoids, that the fat of milk must be formed in the same way. Disallowing the legitimacy of such a deduction, there do, nevertheless, seem to be reasons for supposing that the fat of milk may, at any rate in large proportion, be derived from albuminoids.

Thus, as compared with fattening increase, which may in a sense be said to be little more than an accumulation of reserve material from excess of food, milk is a special product, of a special gland, for a special normal exigency of the animal. Further, whilst common experience shows that the herbivorous animal becomes the more fat, the more, within certain limits, its food is rich in carbohydrates, it points to the conclusion that both the yield of milk, and its richness in butter, are more connected with a liberal supply of the nitrogenous constituents in the food. Obviously, so far as this is the case, it may be only that thereby more active change in the system, and therefore greater activity of the special function, is maintained. The evidence at command is at any rate not inconsistent with the supposition that a good deal of the fat of milk may have its source in the breaking up of albuminoids, but direct evidence on the point is still wanting; and, supposing such breaking up to take place in the gland, the question arises—What becomes of the by-products? Assuming, however, that such change does take place, the amount of nitrogenous substance supplied to the Rothamsted cows would be less in excess of the direct requirement for milk-production than the figures in the table would indicate—if, indeed, in excess at all.

The figures in the column relating to the estimated amount

of digestible non-nitrogenous substance reckoned as starch, show that the quantity actually consumed was 11·71 lb., whilst the amount estimated by Wolff to be required was 12·5 lb., besides 0·4 lb. of fat. The figures further show that, deducting 7·4 lb. for sustenance from the quantity actually consumed, there would remain 4·31 lb. available for milk-production, whilst only about 3·02 lb. would be required supposing that both the fat of the milk and the sugar had been derived from the carbohydrates of the food; and, according to this calculation, there would still be an excess in the daily food of 1·29 lb.

It is to be borne in mind, however, that estimates of the requirement for mere sustenance are mainly founded on the results of experiments in which the animals are allowed only such a limited amount of food as will maintain them without either loss or gain when at rest. But physiological considerations point to the conclusion that the expenditure, independently of loss or gain, will be the greater the more liberal the ration; and hence it is probable that the real excess, if any, over that required for sustenance and milk-production would be less than that indicated in the table, which is calculated on the assumption of a fixed requirement for sustenance for a given live-weight of the animal.

Supposing that there really was any material excess of either the nitrogenous or the non-nitrogenous constituents supplied over the requirement for sustenance and milk-production, the question arises—whether, or to what extent, it conduced to increase in live-weight of the animals, or whether it was in part or wholly voided, and so wasted?

It would obviously be of interest to trace the connexion between variation in the quantity and composition of the food, and the quantity and composition of the milk yielded. But when the influence on the result of breed, of varying character of individual animals, of period of lactation, and of other circumstances, is borne in mind, it will be seen that to treat the subject at all adequately would involve a great deal of detailed illustration and consideration, and occupy very much more space than could appropriately be devoted to it in this place. We must, indeed, limit further reference to the subject of milk-production to one more illustration, showing the influence of period of the year, with its characteristic changes of food, on the quantity and composition of the milk.

The first column of the second division of Table X. shows the average yield of milk per head per day of the Rothamsted herd, averaging about 42 cows, almost exclusively

Shorthorns, in each month of the year, over six years, 1884–1889 inclusive; and the succeeding columns show the amounts of butter-fat, of solids not fat, and of total solids, in the average yield per head per day in each month of the year, calculated, not according to direct analytical determinations made at Rothamsted, but according to the results of more than 14,000 analyses made, under the superintendence of Dr. Vieth, in the laboratory of the Aylesbury Dairy Company, in 1884; [1] the samples analysed representing the milk from a great many different farms in each month.

TABLE X.—*Percentage Composition of Milk each Month of the Year; also Average Yield of Milk, and of Constituents, per Head per Day, each Month, according to Rothamsted Dairy Records.*

—	Average composition of milk each month, 1884 (Dr. Vieth—14,235 analyses)				Rothamsted Dairy			
	Specific gravity	Per cent.			Average yield of milk per head per day, 6 years	Estimated quantity of constituents in milk per head per day each month		
		Butter-fat	Solids not fat	Total solids		Butter-fat	Solids not fat	Total solids
		Per cent.	Per cent.	Per cent.	lb.	lb.	lb.	lb.
January . .	1·0325	3·55	9·34	12·89	20·31[1]	0·72	1·90	2·62
February . .	1·0325	3·53	9·24	12·77	22·81	0·80	2·11	2·91
March . .	1·0323	3·50	9·22	12·72	24·19	0·85	2·23	3·08
April . .	1·0323	3·43	9·22	12·65	26·50	0·91	2·44	3·35
May . . .	1·0324	3·34	9·30	12·64	31·31	1·05	2·91	3·96
June . .	1·0323	3·31	9·19	12·50	30·81	1·02	2·83	3·85
July . . .	1·0319	3·47	9·13	12·60	28·00	0·97	2·56	3·53
August . .	1·0318	3·87	9·08	12·95	25·00	0·97	2·27	3·24
September .	1·0321	4·11	9·17	13·28	22·94	0·94	2·11	3·05
October . .	1·0324	4·26	9·27	13·53	21·00	0·89	1·95	2·84
November .	1·0324	4·36	9·29	13·65	19·19	0·84	1·78	2·62
December .	1·0326	4·10	9·29	13·39	19·31	0·79	1·79	2·58
Mean .	1·0323	3·74	9·22	12·96	24·28	0·90	2·24	3·14

[1] Average over 5 years only, as the records did not commence until February 1884.

It should be stated that the Rothamsted cows had cake throughout the year; at first 4 lb. per head per day, but afterwards graduated according to the yield of milk, on the basis of 4 lb. for a yield of 28 lb. of milk, the result being that then the amount given averaged more per head per day during the grazing period, but less earlier and later in the year. Bran, hay and straw-chaff, and roots (generally mangel), were also given when the animals were not turned out to grass. The

[1] *The Analyst*, April, 1885, vol. x, p. 67.

general plan was, therefore, to give cake alone in addition when the cows were turned out to grass, but some other dry food, and roots, when entirely in the shed during the winter and early spring months.

Referring to the column showing the average yield of milk per head per day each month over the six years, it will be seen that during the six months—January, February, September, October, November, and December—the average yield was sometimes below 20 lb., and on the average only about 21 lb. of milk per head per day; whilst over the other six months it averaged 27·63 lb., and over May and June more than 31 lb., per head per day. That is to say, the quantity of milk yielded was considerably greater during the grazing period than when the animals had more dry food, and roots instead of grass.

Next, referring to the particulars of composition, according to Dr. Vieth's results, which may well be considered as typical for the different periods of the year, it is seen that the specific gravity of the milk was only average, or lower than average, during the grazing period, but rather higher in the earlier and later months of the year. The percentage of total solids was rather lower than the average at the beginning of the year, lowest during the chief grazing months, but considerably higher in the later months of the year, when the animals were kept in the shed, and received more dry food. The percentage of butter-fat follows very closely that of the total solids, being the lowest during the best grazing months, but considerably higher than the average during the last four or five months of the year, when more dry food was given. The percentage of solids not fat was considerably the lowest during the later months of the grazing period, but average, or higher than average, during the earlier and later months of the year.

It may be observed that, according to the average percentages given in the table, a gallon of milk will contain more of both total solids and of butter-fat in the later months of the year; that is, when there is less grass and more dry food given.

Turning now to the last three columns of the table, it is seen that although, as has been shown, the percentage of the several constituents in the milk is lower during the grazing months, the actual amounts contained in the quantity of milk yielded per head are distinctly greater during those months. Thus, the amount of butter-fat yielded *per head per day* is above the average of the year from April to September inclusive; the amounts of solids not fat are over average from April to August inclusive; and the amounts of total solids yielded are average or over average from April to August inclusive.

From the foregoing results, it cannot be doubted that the quantity of milk yielded per head is very much the greater during the grazing months of the year; but that the percentage composition of the milk is lower during that period of higher yield, and considerably higher during the months of more exclusively dry-food feeding. Nevertheless, owing to the much greater quantity of milk yielded during the grazing months, the actual quantity of constituents yielded per cow is greater during those months than during the months of higher percentage composition, but lower yield of milk per head. It may be added, that a careful consideration of the number of newly calved cows brought into the herd each month, shows that the results as above stated were perfectly distinct, independently of any influence of the period of lactation of the different individuals of the herd.

The few results which have been brought forward in relation to *milk-production* are admittedly quite insufficient adequately to illustrate the influence of variation in the quantity and composition of the food on the quantity and composition of the milk yielded. Indeed, owing to the intrinsic difficulties of experimenting on such a subject, involving, as has been pointed out, so many elements of variation beside those which it is sought to investigate, any results obtained have to be interpreted with much care and reservation. Nevertheless, exercising such care and reservation in regard to the numerous results of ourselves and others which are at command, it may be taken as clearly indicated that, within certain limits, high feeding, and especially high nitrogenous feeding, does increase both the yield and the richness of the milk. But it is evident that, when high feeding is pushed beyond a comparatively limited range, the tendency is to increase the weight of the animal; that is, to favour the development of the individual, rather than to enhance the activity of the functions connected with the reproductive system. This is, of course, a disadvantage when the object is to maintain the milk-yielding condition of the animal; but when a cow is to be fattened off it will be otherwise.

It has been stated that, early in the period of six years in which the Rothamsted results that have been quoted were obtained, the amount of oil-cake given was graduated according to the yield of milk of each individual cow; as it seemed unreasonable that an animal yielding, say, only 4 quarts per head per day, should receive, beside the home foods, as much cake as one yielding several times as much. The obvious supposition is, that any excess of food beyond that required for sustenance

and milk-production would tend to increase the weight of the animal, which, according to the circumstances, may or may not be desirable. But there remains the important question—whether the period of lactation is lengthened, or the yield of the higher yielding cows is maintained the longer, by an increased amount of food? or whether, on the other hand, the period of lactation, or the yield of milk, is reduced by the limitation of the supply of food? The point is at any rate deserving of careful experiment and observation.

It may be observed that direct experiments at Rothamsted confirm the view, arrived at by common experience, that roots, and especially mangel, have a favourable effect on the flow of milk. Further, the Rothamsted experiments have shown, that a higher percentage of butter-fat, of other solids, and of total solids, was obtained with mangel than with silage as the succulent food. The yield of milk was, however, in a much greater degree increased by grazing than by any other change in the food; and with us, at any rate, the influence of roots comes next in order to that of grass, though far behind it, in this respect. But with grazing, as has been shown, the percentage composition of the milk is considerably reduced; though, owing to the greatly increased quantity yielded, the amount of constituents removed in the milk whilst grazing may, nevertheless, be greater per head per day than under any other conditions.

Lastly, it has been clearly illustrated how very much greater is the demand upon the food, especially for nitrogenous and for mineral constituents, in the production of milk than in that of fattening increase.

Food and Manure.

At the commencement of this paper it was shown, by reference to a special example, how large was the proportion of the constituents of the crops grown in a rotation which was retained on the farm for further use—in fact, for consumption by animals, or for litter. It was shown that, in the case selected for illustration, there would be so retained on the farm for such further use more than two-thirds of the total vegetable substance grown, more than half of the nitrogen of the crops, and about six-sevenths of the total mineral matter; whilst, of the individual mineral constituents of the crops, less than half of the phosphoric acid but about four-fifths of the potash, would be retained.

Of course, in the very varied practice of Agriculture at the present day there will sometimes be larger, and sometimes

smaller, proportions of the various constituents of the crops at once sold off, or retained on the farm; but the example given may be taken as essentially typical, and as so far conveying a very useful impression on the subject. But, besides the constituents of the home-grown rotation crops retained upon the farm for food and litter, there will be more or less produce from grass land, whilst modern practices frequently involve the purchase of a considerable quantity of imported food-stuffs.

Results relating to the feeding of animals for the production of meat, and of milk, have been considered; and we have now to discuss the subject of feeding as a source of manure. Numerous Rothamsted experiments have shown how small is the proportion of the various constituents consumed in food by fattening, or even by growing animals, which is stored up in their increase, and which will therefore be lost to the manure. In the production of milk, however, it has been seen that the loss to the manure is very much greater.

Of the mineral matters of the food, we know that there need be no loss to the manure beyond that carried off in the animal increase or in milk. Of the non-nitrogenous organic substance of the food, a very large proportion is lost by the respiration of the animals, and a not inconsiderable quantity contributes to the animal increase or milk; and what remains for manure, is of no material value as a direct supply of constituents, and of comparatively little by the action of its products of decomposition within the soil. Indeed, the most important point to consider is —What proportion of the *nitrogen* of the food remains for manure? As has been shown, and as will be further illustrated presently, only a comparatively small proportion is carried off in animal increase; but a much larger amount is lost to the manure in the production of milk. But the further questions arise—Is there any, so to speak, vital exhalation of nitrogen, or of any compounds of it, by the animal? Or, may we estimate that the whole of that consumed which is not carried off in the animal increase, or in milk, will be found in the solid and liquid dejections, and so remain for manure? Or, on the other hand, Is there any assimilation by the animal of the free nitrogen of the atmosphere? The further practical question still remains—Is there any material loss of nitrogen after the solid and liquid excretions leave the body, and before their utilisation within the soil for the production of future crops?

First then, Is there any vital exhalation by the animal of nitrogen or of any of its compounds?

Obviously, this is a question which could not be experimentally investigated before definite knowledge was attained in

regard to the composition of the atmosphere. But after such knowledge had been acquired, rather more than a century ago, the subject of the mutual relations of the atmosphere, and of vegetable and animal growth, came to be studied; and, among other points, it was sought to determine whether, on the one hand, the free nitrogen was assimilated by animals? or, on the other, whether it was exhaled, at the expense of the nitrogenous substance of the food, of the blood, or of the more fixed substance of the body?

Commencing towards the end of the last century, numerous investigations have been undertaken, from various points of view, bearing upon the subject; and among the investigators or writers may be named—Lavoisier, Laplace, Séguin, Dalton, Sir H. Davy, Pfaff, Provençal and Humboldt, Allen and Pepys, Despretz and Dulong, Brunner and Valentin, Marchand, von Erlach, Baumert, Regnault and Reiset, Berthollet, Milne-Edwards, and C. G. Lehmann; besides others more recently.

It is impossible shortly, and at the same time adequately, either to describe or to criticise the numerous and, upon the whole, discordant results, that have been obtained in regard to the question of the assimilation or exhalation of free nitrogen by animals. It is noticeable that the earlier investigators, Lavoisier, Laplace, and Séguin, concluded that the amount of nitrogen expired was neither more nor less than that inspired; and in this view they are in the main supported by the conclusions, though not entirely by the results, of Allen and Pepys, of Brunner and Valentin, and von Erlach. In favour of the view that free nitrogen is absorbed and assimilated may be cited the opinions of Sir Humphry Davy and of Pfaff, so far as certain warm-blooded animals are concerned; and of Provençal and Humboldt, and of Baumert, in regard to fish. On the other hand, that there is evolution of free nitrogen has been concluded by Sir H. Davy, Berthollet, Dulong and Despretz, Magnus, Marchand, Grassi, Regnault and Reiset, and C. G. Lehmann.

In regard to evolution, the most extensive and elaborate experiments are those of Regnault and Reiset. But the amounts which their results indicated would imply the loss in that way of an incredibly large proportion of the total nitrogen consumed in the food; whilst Liebig estimated that the evolution which Dulong assumed was so great that, in the case of one of the experimental animals, the whole of the nitrogen of the body would be lost in seven days; and that, at the rate assumed by Despretz, the nitrogen of one pound of flesh would go off in thirty-one hours.

Then, the results indicating absorption are the most

pronounced in the experiments with fish. The question arises, therefore, whether in their case the result may not be explained by supposing that oxygen has been absorbed from the air within the body, especially in the swimming bladder, and nitrogen stored up in its place, under the conditions of limited supply of oxygen from external sources to which the animals have generally been subjected during experiment.

Upon the whole it must be concluded that, from a variety of causes, connected sometimes with the conditions under which the animals were placed under experiment, sometimes with the circumstances under which the samples assumed to represent the inspired and expired air respectively were taken for analysis, and sometimes with the methods of analysis themselves, the results of the experiments on respiration which have been referred to, have not been sufficiently free from doubt to be accepted as establishing so important a conclusion as either the assimilation of free nitrogen by animals, or the evolution of it from its compounds within the body.

The next point to consider is—whether there is any loss of ammonia, or of other compounds of nitrogen, in the breath, or by the skin.

Louis Thompson, Thiry, Grouven, and others, have found some emanation of ammonia; but Lossen, and others, consider it doubtful whether the ammonia in the air itself might not account for the results.

Various experiments have been made to determine the loss of nitrogen in sweat. In the sweat of man, ammonia and urea have been found. In the sweat of a horse, Grandeau and Leclerc[1] found ammonia, urea, and albumin. Professor F. Smith, of Aldershot,[2] has also examined the sweat of horses. Besides various inorganic salts, he found ammonia, and 3·381 per cent. of albumin. He reckons that a pint of sweat will thus contain 0·676 ounce of albumin, and that this amount would be equivalent to the nitrogen in 5¾ ounces of oats. He further thinks it probable that the reduction of sweating by clipping would, with hard work, be equivalent to 1 lb. of corn per day.

It seems safe to conclude, that the loss of combined nitrogen by gaseous emanations from the lungs and skin is, for all practical purposes, quantitatively immaterial. The sweat would seem to be a more important source of loss in animals submitted to much muscular exercise. But, even in their case, it does

[1] *Annales de la Science agronomique*, 5me année, 1888, tome ii., pp. 311–314.
[2] *Journal of Physiology*, 1890, vol. xi. p. 497.

not seem to be large; whilst in that of the animals of the farm fed for the production of meat or milk it would presumably be much less material.

We now come to the consideration of evidence of quite another kind as to the loss to the manure of the nitrogen of the food, beyond the amount stored up in increase, or removed in milk: namely, that afforded by the results of experiments made to determine the relation of the amount of nitrogen voided in the solid and liquid excretions, to that consumed in the food. Most of these have been made with the animals of the farm; indeed, most of them have had for their object the direct determination of the amount of the nitrogen of the food consumed which is recovered in the manure in practical feeding. The chief results may be very briefly summarised as follows:—

Boussingault made experiments[1] with a cow, with a horse, and with turtle-doves (probably between 1830 and 1840).

In the experiment with a cow, the animal was fed on the same food for about a month, and the results relate to the three concluding days of that period. Boussingault observes that the animal did not suffer any material change in weight. Besides the nitrogen removed in the milk, there was an amount not recovered in the excrements which represented a loss of 13·4 per cent. of the total nitrogen of the food.

In the experiment with a horse, the animal had received the same ration for three months, and did not either gain or lose in weight appreciably. There was here again an amount unaccounted for, representing a loss of 17·2 per cent. of the nitrogen of the food.

In the two experiments with turtle-doves, one over five and the other over seven days, each of the birds rather lost weight. Their food was millet; and in the one case there was a loss of 35·9, and in the other of 34·1, per cent. of the nitrogen in the food. Boussingault thought that there was undoubtedly a loss of nitrogen, as the amount unrecovered was far too great to be accounted for by errors of analysis.

Experiments were made on the subject at Rothamsted, in 1854, with pigs. Individual male animals were experimented upon for periods of three and of ten days. Each animal was kept in a frame, preventing it from turning round, and having a zinc bottom sloping slightly from each side towards the centre, where there was an outlet for the urine to run into a bottle

[1] *Agronomie, Chimie agricole et Physiologie*, 2nd ed., 1874, vol. v. p. 144.

beneath. They were watched night and day, and the voidings carefully collected as soon as passed; which could easily be done, as the animals never passed either fæces or urine without getting up, and in so doing rang a bell, and thus attracted the notice of the attendant. The constituents determined were—in the food and fæces, dry matter, ash, and nitrogen; and in the urine, dry matter, ash, nitrogen, and urea. In preparing samples of fæces or of urine for nitrogen determinations, a mixture was made of a proportional part of the voiding of each twenty-four hours, and oxalic acid added. In the case of the fæces, portions of the acid mixture were taken for the determination of dry matter; and nitrogen determinations were made in the partially dried substance, and calculated up to the fully dried condition. In the case of the urine, portions of the acid mixture were fully dried, and other portions partially dried, and then mixed with about half the weight of fully dried oak-dust, in which the nitrogen was determined.

Over a preliminary period, and also over each period of exact experiment, one animal received the highly nitrogenous lentil-meal, and the other the low-in-nitrogen barley-meal. In each case, the one receiving lentil-meal consumed more than twice as much nitrogen in food, and voided more than twice as much in the solid and liquid excrements.

Notwithstanding the great attention paid to the collection, the sampling, and the preparation of the samples of the excrements for nitrogen determinations, as above described, there was, in each case, a considerable amount of the nitrogen of the food unaccounted for in that estimated in the increase, and in that found in the excrements. There was, too, a much greater loss indicated by the results of the direct nitrogen determinations in the urine dried with an excess of oxalic acid, than when the nitrogen was calculated from the amount of urea found daily in the fresh urine. As, however, nitrogen determinations (by soda-lime and platinum salt) were made by two analysts, whose results agreed very fairly, it may be concluded that the loss was connected with the methods of collection, sampling, and preparation for analysis, rather than with those of the analysis; and it is probable that the same remark applies to the results obtained with the fæces. In illustration of the range of loss of nitrogen indicated, it may be stated that when the nitrogen in the urine was reckoned from the amount of urea, the loss ranged in the four experiments between 20 and 30 per cent. of that in the food, and when by direct nitrogen determinations in urine, as well as in fæces, from under to over 40 per cent. However, in the case of each food, whether the

nitrogen in the urine was determined, or calculated from the urea, there was considerably less loss indicated over the ten-day than over the shorter three-day periods; again connecting the error with the collection, sampling, and preparation, rather than with the analysis.

In view of these unsatisfactory results, and of the evidence that much, at any rate, of the loss was probably due to experimental difficulties and errors, the subject was taken up again in 1862. The pigs were kept in frames as before, and the voidings were collected in the same way; but they were sampled morning and evening, instead of only once in the twenty-four hours, as in 1854. Advantage was also taken of the previous experience in regard to various other points of manipulation. Lastly, the direct nitrogen determinations were made by soda-lime as before, but with titration instead of platinum salt.

Two animals were experimented upon, each for a period of ten days, and, after an interval of a few weeks, for five days more. The food of one consisted of three parts bean-meal and one part bran, and of the other of three parts barley-meal and one part bran.

In the case of the pig having the highly nitrogenous bean-meal and bran, the nitrogen balance for the ten days showed a gain of 4·04 per cent. when direct nitrogen determinations were made in the urine, and of only 2·32 per cent. when the nitrogen in the urine was calculated from the amount of urea. On the other hand, over the five-day period there was a loss indicated of 3·35 per cent. with the direct nitrogen determinations in the urine, and of only 1·61 per cent. when the nitrogen was calculated from urea. In the latter case, therefore, the amount of nitrogen accounted for was again less with direct determination than by calculation from urea.

In the case of the pig having the low-in-nitrogen barley-meal, and bran, there was, over the ten-day period, a loss indicated of 7·16 per cent. of nitrogen with direct determination, and of only 4·90 per cent. when the nitrogen was calculated from the urea. In this case, therefore, there was again less loss of nitrogen by calculation from urea than by direct determination. Lastly, over the five-day period there was, with the barley-meal and bran, a gain of nitrogen indicated of 7·76 per cent. with direct determination of nitrogen in the urine, and of 11·02 per cent. when calculated from the urea. In both cases, therefore, there was more nitrogen accounted for by calculation from urea than by direct determination.

These results obtained in 1862 show, therefore, with the beans and bran, a slight gain over the ten days, and a slight

loss over the five days. On the other hand, with the barley and bran there was a comparatively small loss over the ten days, and a somewhat greater gain over the five days.

When the fact that there was a much greater variation in the amounts of the daily voidings than in those of the food daily consumed, and also the uncertainty in the estimation of the proper increase of the animals over short periods and of the nitrogen in it, are taken into account, these results must be admitted to afford no evidence of any real loss to the manure of the nitrogen of the food, beyond that in the increase and in the excrements.

The next results to consider were obtained at Rothamsted in 1861, with sheep. There were four pens with five sheep in each. Besides the determination of the total dry matter, ash, and nitrogen, in the food and in the excrements, one special object was to determine what proportion of the cellulose of the food was digested; and whether more or less was so utilised according to the character of the foods given with it. Accordingly, foods containing a comparatively large amount of cellulose were selected, as under:—

Pen 1. Meadow-hay-chaff alone, *ad libitum*.
„ 2. 1 lb. of ground beans per head per day, and meadow-hay-chaff *ad libitum*.
„ 3. 1 lb. of ground barley per head per day, and meadow-hay-chaff *ad libitum*
„ 4. About 6½ oz. of ground beans, and about 3½ oz. of linseed oil, per head per day, and meadow-hay-chaff *ad libitum*.

In Pen 4 the object was to give an amount of beans containing the same quantity of nitrogen as the barley of Pen 3, and then to make up the deficiency of starch in the smaller quantity of beans compared with that in the barley by oil, in the proportion of 1 part of oil for 2½ parts of starch.

With a view to the careful collection, sampling, and analysis of the excrements, the sheep were kept under cover, on rafters, through which (but with some loss) the solid and liquid excreta passed on to a sheet-zinc flooring, at such an incline that the liquid drained off at once into carboys containing oxalic acid; and the solid matter was removed two or three times daily, and also mixed with oxalic acid.

After a preliminary period of eight weeks the exact feeding experiment was continued for thirty-two weeks more, from January 25 to September 6. Commencing on March 26, and ending on August 9, samples of the excrements were taken at intervals, in each case for several consecutive days, namely, 4, 5, 5, 7, 7, 7, 7, 7, 7 and 7 days; and the results here

given are the means of the seven 7-day periods. The amounts of nitrogen so indicated to be not recovered in either the increase or in the excreted matters were, in the four pens, respectively 12·5, 25·4, 15·2, and 17·7 per cent. of the nitrogen supplied in the food. It is to be observed that the estimated loss is the greatest with the most, and the least with the least, nitrogen in the food. The question arises—whether the greater estimated loss is connected with an under-estimate of the nitrogen in the increase of the animals feeding on the more highly nitrogenous food, or with an actually greater loss from decomposition in the case of the more highly nitrogenous excrements.

In 1858, Henneberg [1] made experiments with 2 oxen, each separately. The animals were kept on sustenance food only. After a preliminary period of several weeks, there were three periods of more exact experiment—the first from February 27 to March 27, the second from March 28 to May 21, and the third from May 22 to July 15; and during 3 days towards the end of each of these periods the excrements were collected and analysed. Ox No. 1 gained 6 lb. during the three days of the first period, 1 lb. during those of the second, and 11 lb. durins those of the third. The percentage of the nitrogen of the food which was not recovered in the excrements was, for the respective three-day periods, 5·7, 28·8, and 15·1, or an average of 16·5. Ox No. 2 neither gained nor lost during the first three-day period, lost 3 lb. during the second, and 8 lb. during the third; and the analyses of the excrements showed a gain of nitrogen compared with that in the food of 9·6 per cent. over the first three days, a loss of 24·7 per cent. over the second three, and a gain of 6·3 per cent. over the third. That is to say, Ox No. 1, with more or less gain over each of the three-day periods—which may perhaps be interpreted as retention in the alimentary canal or bladder rather than increase in the substance of the body—showed a considerable deficit of nitrogen in the excrements compared with that in the food. Ox No. 2, on the other hand, with loss of weight—which probably only represented more complete evacuation in relation to the food consumed—indicated more of tendency to excess of nitrogen in the excrements compared with that in the food. In experiments in 1860–61, also with two bullocks, Henneberg found, this time over six-day instead of three-day periods, deficits of nitrogen in the excrements corresponding to the following percentages of the amounts supplied in

[1] *Beiträge zur Begründung einer rationellen Fütterung der Wiederkäuer*, Heft 1, 1860.

the food—35, 37, 21, 12, 10, 0. It may be observed that the percentage of loss was, upon the whole, the greater with the larger amounts of nitrogen in the food. Later results of Henneberg will be referred to further on.

In none of the foregoing experiments, either by Boussingault, at Rothamsted, or by Henneberg, was any litter used, the excrements being collected and analysed by themselves.

In 1851 we made experiments with oxen, at Woburn Park Farm, by the permission of the Duke of Bedford. In the experiment, the results of which are given below, there were five Herefords, each in a separate box, and the experimental period extended over thirty-five days. Liberal fattening food was given, consisting of a cooked mixture of equal parts of ground oil-cake, barley, and beans, besides clover-hay-chaff, and swedes. The litter consisted of wheat-straw; and an absorbent, composed of 2 parts sawdust and 1 part sulphuric acid, was used; a small quantity being daily sprinkled over the manure in the boxes just before spreading the fresh litter. At the end of the experiment the whole of the dung was got out, put into a large shed, turned over by men, pulled to pieces by boys, and thoroughly mixed; and in that state it was weighed, and several separate 100-lb. samples were taken, each being put into a clean cask, in which state the samples were sent to Rothamsted for analysis. In the preparation for analysis, the whole of the 100-lb. sample was coarsely ground, then divided into portions, one or more of which was finely ground for analysis, and in the sample so prepared the nitrogen was determined by the soda-lime method. It was so determined separately in samples from two of the 100-lb. casks. Deducting the amount of nitrogen in the increase (reckoning it to contain 1·27 per cent.), there was a deficiency of nitrogen in the dung, compared with that in the food and litter—according to one 100-lb. sample, of 8·03, and to the other, or duplicate one, of 10·55 per cent.

Such, then, were the results of the earlier experiments, made by various investigators, to determine whether or not there was any loss of nitrogen in the feeding of animals beyond that stored up in their increase. It will be observed that, with the exception of the turtle-doves experimented upon by Boussingault, all the other results were obtained with the animals of the farm; and in all cases, excepting those of the experiments at Rothamsted with pigs and with sheep, and at Woburn with oxen, the animals were assumed to be fed on only sustenance rations, and no allowance was made in the calculations for any increase or loss in their weight. It has been seen that, in every case excepting in the experiment with Henne-

berg's Ox No. 2, and in the experiments at Rothamsted with pigs in 1862, the figures indicate a notable, and in some a very considerable, loss of nitrogen; which, assuming it to be not explained by storing up of nitrogen in the animal, or deficient evacuation, might be supposed to point to a probable loss by respiration, or perspiration, or both.

From a study in much detail of the direct experiments on respiration and perspiration which have been referred to, we ourselves have been disposed to conclude that there was no material exhalation of either free nitrogen or of its compounds. Further, notwithstanding our own early results with pigs, those with sheep, and those at Woburn with oxen, all indicated more or less—and sometimes a considerable—loss, the observations made during the conduct of the investigations so fully impressed us with the liability to error, especially on the side of loss, that we have always considered it doubtful whether there was in reality any material loss at all. In the first place, there is the uncertainty in the estimation of the changes in the weight of the body—whether to attribute them to increase or loss of its fixed substance, or to excess or deficiency in the evacuations in relation to the food consumed within the period of experiment; and there are, besides, great difficulties to be overcome, both in the complete collection, the proper sampling, and the preparation, without change, of the excreted matters; and there are also special difficulties in the adaptation of analytical methods to secure exact representative results. Indeed, most of the results so far quoted, whether of ourselves or others, must be looked upon as little more than pioneer; though, taken as such, the experience gained has proved to be of essential value in directing attention to the difficulties and sources of error incident to such work, and to the improvement in methods of collection, sampling, preparation, and analysis.

For ourselves, being satisfied that much, if not the whole, of the losses that had been indicated was to be explained by the methods of experimenting, and being very fully occupied with other subjects, we decided, after our experiments with pigs in 1862, not to devote the very great amount of time and labour that would be involved in the repetition of the investigation with still further precautions.

In Germany, however, Henneberg and his colleagues (G. Kühn, H. Schultze, and B. Schultz), at Weende, as well as others, continued to work on the subject with the animals of the farm. Henneberg[1] pointed out that the experiments of Bischoff

[1] *Neue Beiträge*, Göttingen, I., 373–375, 1872.

and Voit with dogs in 1859,[1] of Ranke with man in 1860–1,[2] of Voit with pigeons in 1860–2,[3] and of Pettenkofer and Voit with man,[4] showed almost complete re-appearance of the nitrogen of the food in the solid and liquid excretions; and, if this were the case with carnivora and omnivora, there seemed no reason why it should not be so with herbivora. He further pointed out how small an actual loss or gain in the determined amount of nitrogen in the fæces or the urine might make a great difference in the balance; and he admitted that more attention than had hitherto been given to certain points must in future be devoted; as, for instance, to the rinsing and washing of the stalls, and to the determination of the dry matter in the food, fæces, and urine, more frequently, and uniformly throughout the experimental period.

In the Weende experiments of 1865, and subsequently, more attention was paid to such points, and the periods of exact experiment were longer. There was, accordingly, great improvement in the results. Thus, in a series of 8 experiments with oxen, in 5 with only sustenance or maintenance rations, the result was that, in three of them the percentage deficit of nitrogen in the excrements compared with that in the food was 0·4, 2·7, and 2·2; whilst in the other two there was a gain representing 0·8 and 3·7 per cent. In the three other experiments, fattening food containing about twice as much nitrogen was given, and in these the deficits in the excrements were 12·1, 12·0, and 17·7 per cent. of the nitrogen in the food. Henneberg concluded that, with only sustenance rations, the whole of the nitrogen of the food of oxen reappeared in the excrements, and that it was no longer necessary to infer from the results obtained with other animals what would take place with ruminants.

Henneberg also quotes results[5] obtained with cows by Voit at Munich, by G. Kühn and Fleischer at Möckern, and by Fleischer at Hohenheim. Voit's results, obtained in 1867, showed a deficit of nitrogen in the milk, fæces, and urine, representing 1·2 per cent. of that in the food. In 8 experiments made at Möckern in 1867–8 with cows, six showed respectively losses corresponding to 2·9, 11·1, 3·8, 5·6, 16·4, and 7·0 per cent. of the nitrogen in the food; and the other

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[1] *Die Gesetze der Ernährung des Fleischfressers*, Leipzig, 1860.

[2] *Archiv für anat. phys. und wissenschaftliche Medicin*, Leipzig, 1862, p. 311.

[3] *Annalen*, II. Suppl. p. 238, 1862.

[4] *Zeits. f. Biol.*, II. p. 459.

[5] *Neue Beiträge*, Heft I., p. 383, 1872.

two showed gains corresponding to 1·2 and 4·8 per cent. In the case of the larger losses more nitrogen was consumed in the food, and the animals gained in weight, and presumably stored up nitrogen. At Hohenheim, in 1870, experiments were made by Fleischer with two cows, one of which showed a loss of 0·3, and the other a gain of 0·6, per cent. of nitrogen compared with that in the food.

Experiments were also made with sheep, by Maercker and E. Schulze, at Weende,[1] which confirmed the conclusions drawn from those with oxen and cows as above, as also did others made by Stohmann with goats[2] at the Halle experimental station.

We will conclude the citation of experimental evidence on the point by reference to some of the results obtained by Voit from 1859 to 1863 with dogs.[3] In none of these cases was the period of exact experiment less than 6 days, whilst in some it was 12, 14, 20, 23, 49, and even 58 days. In 8 out of the 11 cases there was an excess of nitrogen in the excrements compared with that in the food, representing the following percentages of gain on that in the food—1·0, 0·7, 0·4, 0·4, 0·6, 0·3, 0·1, and 0·1; whilst the deficits represented 1·4, and 0·3 per cent., and one experiment showed neither gain nor loss.

Since the publication of the various results above quoted there has been little doubt entertained that, not only in the case of carnivora and omnivora, but also in that of herbivora, and even of ruminants, practically the whole of the nitrogen of the food which does not contribute to animal increase or to milk, reappears in the excrements.

In our estimates of the value of the manure from the consumption of different foods by animals on the farm, so far as the nitrogen was concerned, we many years ago deducted 10 per cent. from the amounts consumed in oilcakes and leguminous seeds, which contain high percentages of nitrogen, and 15 per cent. from the amounts in the foods which contain lower percentages. These deductions were reckoned to include the amounts of nitrogen actually stored up in the increase of live-weight, and also some little loss if any, but not to cover the larger losses that may take place in the manure after it is voided by the animals. More recently, however, we have estimated the amount actually stored up in the animal, and have

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[1] *Journ. f. Landw.* 1870 and 1871; Armsby, *Manual of Cattle-feeding*, 3rd ed., 1887, pp. 99–100.

[2] *Zeits. f. Biol.*, 1870, p 204; Armsby, *loc. cit.*, pp. 100–101.

[3] Bischoff and Voit, *Die Gesetze der Ernährung des Fleischfressers*, 1860; and Wolff's *Die Ernährung d. landw. Nutzthiere*, 1876.

assumed the whole of the remainder to be voided in the solid and liquid excretions.

For details on the point we must refer to our most recent paper bearing upon the subject, entitled—*On the Valuation of Unexhausted Manures.*[1] The calculations relate to the use of food for the production of fattening increase. It is assumed that, on the average, such increase will contain 8 per cent. of nitrogenous substance, corresponding to 1·27 per cent. of nitrogen in the increase. According to the calculations it results that, of the total nitrogen consumed in foods rich in that substance, such as oilcakes and leguminous seeds, there will generally be less than 5 per cent. retained in the fattening increase in live-weight. In the case of the cereal grains, on the other hand, which are much less rich in nitrogen, a much larger proportion of the total amount consumed will be retained in the increase—generally perhaps about 10 per cent. of it. Of the nitrogen in gramineous straws a still higher proportion will probably be devoted to increase; whilst roots will, on the average, lose by feeding perhaps only about 5 or 6 per cent. of their nitrogen.

Thus, when fattening increase only is produced, the proportion of the nitrogen of the food which will be retained by the animal, and so lost to the manure, is very small in the case of the richer foods, but more in that of the poorer ones; though, even with them, it will seldom exceed 10 per cent., except possibly in the case of straws. It may be assumed, however, that when foods are consumed by store animals, whose increase is largely growth, about twice as much of the nitrogen of the food is retained, and so lost to the manure. And when, as is more and more the case with early maturity, the increase comprises a larger proportion of growth than in mere fattening, the amount of the nitrogen of the food which will be lost to the manure will be more than with fattening only, but less than with merely store animals. When, however, food is consumed for the production of milk, a very much greater proportion of its nitrogen will be lost to the manure.

Food and the Exercise of Force.

We now come to the last branch of our subject, namely—*The Feeding of Animals for the Exercise of Force.* With the very limited space still left at our disposal, we will commence our historical sketch with a brief account of the views of Liebig as

[1] Journal, R.A.S.E., vol. xxi., S. S., Part II., 1885.

first put forward in 1842, in his work—*On Organic Chemistry in its Applications to Physiology and Pathology*. There is indeed a special appropriateness in so doing, since there can be no doubt that the course of subsequent inquiry and discussion has been materially influenced by the opinions he then enunciated.

The following quotations from the above-mentioned work will suffice to indicate his more specific views in regard to the connexion between food requirements and the exercise of force:—

"As an immediate effect of the manifestation of mechanical force, we see, that a part of the muscular substance loses its vital properties, its character of life; that this portion separates from the living part, and loses its capacity of growth and its power of resistance. We find that this change of properties is accompanied by the entrance of a foreign body (oxygen) into the composition of the muscular fibre (just as the acid lost its chemical character by combining with zinc); and all experience proves, that this conversion of living muscular fibre into compounds destitute of vitality is accelerated or retarded according to the amount of force employed to produce motion. Nay, it may safely be affirmed, that they are mutually proportional; that a rapid transformation of muscular fibre, or, as it may be called, a rapid change of matter, determines a greater amount of mechanical force; and conversely, that a greater amount of mechanical motion (of mechanical force expended in motion) determines a more rapid change of matter" (pp. 220–1).

And again:—

"The amount of azotised food necessary to restore the equilibrium between waste and supply is directly proportional to the amount of tissues metamorphosed."

"The amount of living matter, which in the body loses the condition of life, is, in equal temperatures, directly proportional to the mechanical effects produced in a given time."

"The amount of tissue metamorphosed in a given time may be measured by the quantity of nitrogen in the urine."

"The sum of the mechanical effects produced in two individuals, in the same temperature, is proportional to the amount of nitrogen in their urine; whether the mechanical force has been employed in voluntary or involuntary motions, whether it has been consumed by the limbs, or by the heart and other viscera" (p. 245).

Such, in fact, were the views in regard to the special exigencies of the system in the exercise of force which became at once identified with Liebig's name, and continued to be so identified for many years. Thus, Professor Frankland, in his lecture at the Royal Institution in 1866,[1] on the experiments of Fick and Wislicenus,[2] refers to these views of Liebig as having, up to that time, been pretty generally adopted by text-book writers.

[1] *Journ. R. Inst.*, 1866.

[2] *Phil. Mag.*, 1866, 4th eries, vol. xxxi. pp. 485–503.

The results of our own feeding experiments, which were commenced some years after the appearance of Liebig's work, being apparently inconsistent with the then current views on some important points, we were led at once to turn attention to the subject of human dietaries; and also to a consideration of the management of the animal body undergoing somewhat excessive labour, as, for instance, the hunting-horse, the racer, the cabhorse, the foxhound, and also pugilists and runners. The conclusions to which we were led by this study were briefly summarised in a paper published in the *Report of the British Association for the Advancement of Science* for 1852, as follows:—

"... that in the cases, at least of ordinary exercise of force, the exigencies of the respiratory system keep pace more nearly with the demand for nitrogenous constituents of food than is usually supposed;"

And further:—

"A somewhat concentrated supply of nitrogen does, however, in some cases, seem to be required when the system is overtaxed; as, for instance, when day by day more labour is demanded of the animal body than it is competent without deterioration to keep up; and perhaps also, in the human body, when under excitement or excessive mental exercise. It must be remembered, however, that it is in butcher's meat, to which is attributed such high flesh-forming capacity, that we have also, in the fat which it contains, a large proportion of respiratory material of the most concentrated kind. It is found too, that of the dry substance of the *egg*, 40 per cent. is pure fat."

"A consideration of the habits of those of the labouring classes who are under- rather than over-fed, will show that they first have recourse to fat meat, such as pork, rather than to those which are leaner and more nitrogenous; thus perhaps indicating, that the first instinctive call is for an increase of the respiratory constituents of food. It cannot be doubted, however, that the higher classes do consume a larger proportion of the leaner meats; though it is probable, as we have said, that even with these as well as pork, more *fat*, possessing a higher respiratory capacity than any other constituent of food, is taken into the system than is generally imagined. Fat and butter, indeed, may be said to have about twice and a half the respiratory capacity of starch, sugar, &c. It should be remembered, too, that the classes which consume most of the leaner meats, are also those which consume the most butter, sugar, and in many cases, alcoholic drinks also."

"It is further worthy of remark, that wherever labour is expended in the manufacture of staple articles of food, it has generally for its object the concentration of the *non*-nitrogenous, or more peculiarly respiratory constituents. Sugar, butter, and alcoholic drinks are notable instances of this. Cheese, which at first sight might appear an exception, is in reality not so; for those cheeses which bring the highest price are always those which contain the most butter; whilst butter itself is always dearer than cheese."

"In conclusion, it must by no means be understood that we would in any way depreciate the value of even a somewhat liberal amount of nitrogen in food. We believe, however, that on the current views too high a relative importance is attached to it; and that it would conduce to further progress in this most important field of inquiry if the prevailing opinions on the subject were somewhat modified."

It is to be borne in mind, that at the time these opinions were put forward, now more than forty years ago, the views expressed were directly contrary to all recognised authority on the subject; and that it is since that date that so much evidence has been accumulated, as to the amounts of urea, and of carbonic acid, given off under varied conditions as to food and exercise. Still, from the facts already at command, it was concluded that the increased demand for food resulting from the exercise of muscular power was specially characterised by the requirement for an enhanced amount of the non-nitrogenous constituents.

Confirmatory evidence was, however, not long wanting. Thus, in 1854, we selected two pigs as nearly as possible of equal weight and character; to one was given, *ad libitum*, lentil-meal (containing about 4 per cent. of nitrogen), and to the other, also *ad libitum*, barley-meal (containing less than 2 per cent.). Each animal was kept in a frame, with arrangements for collecting the fæces and urine separately, as already described. After they had been kept for a certain time on their respective foods, one comparative experiment was conducted for three days, and later on another for ten days. The weights of the animals were taken at the beginning and at the end of each experiment; and, besides other particulars, the amounts of nitrogen consumed in the food, and of urea voided, were determined. The results are summarised in the following table:—

TABLE XI.—*Experiments at Rothamsted with Pigs. June–August* 1854.

Quantities per head per day.

Periods	Foods	Nitrogen in food	Urea voided	Urea=nitrogen
Days		Grams	Grams	Grams
3	No. 1, Lentil-meal .	123·0	134·0	62·6
3	No. 2, Barley-meal .	58·9	61·5	28·7
10	No. 1, Lentil-meal .	120·6	141·0	65·8
10	No. 2, Barley-meal .	51·2	52·1	24·3

The result was, then, that with exactly equal conditions as to exercise, both animals being in fact at rest, the amount of urea passed by the one feeding on the highly nitrogenous lentil-meal was, in each case, more than twice as great as that voided by the one fed on the barley-meal, supplying less than half the amount of nitrogen.

It was clear, therefore, that the rule laid down by Liebig, and so long generally adopted by others, did not hold good, namely, that—"The sum of the mechanical effects produced in

two individuals in the same temperature is proportional to the amount of nitrogen in their urine; whether the mechanical force has been employed in voluntary or involuntary motions, whether it has been consumed by the limbs or by the heart and other viscera"—unless, indeed, as has been assumed by some experimenters, that there is, with an increase of nitrogenous substance in the food, an increased amount of mechanical force employed in the "involuntary motions" sufficient to account for the increased amount of urea voided.

It was at any rate obvious that, if the amount of urea voided by one animal at rest could be more than twice as great as that voided by a similar animal also at rest, and under otherwise equal conditions, provided only that the food of the one contained more than twice as much nitrogen as that of the other, the amount of urea passed could not be any measure of the amount of muscular power exerted.

The subject was taken up again at Rothamsted in 1862, and accordant results were obtained as follows:—

TABLE XII.—*Experiments at Rothamsted with Pigs. August–September* 1862.

Quantities per head per day.

Period	Foods	Nitrogen in food	Urea voided	Urea = nitrogen
Days		grams	grams	grams
10	No. 1. Barley and bran	41·6	43·6	20·4
10	No. 2. Beans and bran	66·0	89·6	41·8
5	No. 1. Barley and bran	46·2	52·3	24·4
5	No. 2. Beans and bran	82·5	116·6	54·4

Not long after the publication of our views in 1852, and the experiments with pigs in 1854, with the results of which he was acquainted, the late Dr. Edward Smith instituted experiments to determine the amounts of carbonic acid exhaled in respiration under various conditions as to muscular exercise. His results were published in a paper presented to the Royal Society on December 16, 1858.[1] He records the quantities of carbonic acid exhaled in grains per minute, and these we have calculated into grams per hour, and so give them below:—

	Carbonic acid, grams per hour.
During light sleep	19·2
Lying down, scarcely awake	23·0
Sitting quietly	38·1
Walking two miles per hour	70·4
Walking three miles per hour	100·4
On treadwheel, ascending 28·65 ft. per minute	189·2

[1] *Phil. Trans.* 1859, vol. cxlix. pp. 681–742.

There was, therefore, very greatly increased exhalation of carbonic acid with increased muscular exercise.

Dr. E. Smith also conducted experiments on the amounts of urea eliminated under different conditions, both as to food and exercise. The investigation was commenced in January 1860, and continued up to March 1862, a period of two years and two months. These results were also published in a paper in the Philosophical Transactions of the Royal Society.[1] The general result was, that there was great variation in the amount of urea passed when there was concurrent variation in the amount of nitrogenous substance in the food; but, on the other hand, comparatively little variation in the amount of urea voided, with great variation in the amount of labour performed.

Thus, then, Dr. Smith's results, both those showing the amounts of carbonic acid exhaled, and those relating to the amounts of urea voided, fully confirmed the view that with muscular exertion there was marked increase in the demand for the non-nitrogenous, and but little if any in that for the nitrogenous, constituents of food.

Experiments made by Bischoff and Voit in 1858 and 1859[2] with a dog, either submitted to hunger, or fed from time to time on foods containing very different amounts of nitrogenous substance, showed very variable amounts of urea voided, although the animal was kept under equal conditions as to exercise. Still, on the publication of their results in 1860, the authors assumed, that although there had been no greater exercise of force manifested in the form of external work, yet when the amount of nitrogenous substance in the food was greater, and the amount of urea voided correspondingly greater, there must have been a corresponding increase in the force exercised in the conduct of the actions within the body, in connexion with the disposition of the increased amount of nitrogenous substance consumed; so that, after all, the amount of urea eliminated was a measure of the exercise of force, though not in the voluntary exercise of muscular power.

One of us being in Germany in the summer of 1860, and visiting Munich, had some conversation with Professor Voit on the subject of their results and conclusions. Referring to our own results obtained in 1854 with pigs, it was pointed out that they were entirely consistent with those which he and Professor Bischoff had obtained with a dog, but that we had drawn very

[1] *Phil. Trans.*, 1861, vol. cli. pp. 747–834.

[2] *Die Gesetze der Ernährung des Fleischfressers*, 1860.

different conclusions from them. He conveyed the impression, however, that he considered we were entirely in error.

Later in the same year, however, Voit published[1] the results of further experiments with a dog. In these, he submitted the animal to alternate rest and labour, sometimes fasting, sometimes with a moderate, and sometimes with a liberal supply of nitrogenous substance in food. The labour consisted of working in a kind of treadwheel. He found that the amount of urea eliminated was not in proportion to the exercise of force, but was very nearly proportional to the amount of nitrogenous substance consumed. He considered that by such a result the views which he and others had maintained as to the connexion between the exercise of force, the degradation of nitrogenous substance within the body, and the elimination of urea, were completely overturned.

In 1862 Pettenkofer and Voit published a paper[2] giving the results of experiments made with a dog in 1861 and 1862, in which the food consumed, the amount of urea voided, and the quantity of carbonic acid given off by the lungs and skin, were determined; the latter in Pettenkofer's respiration apparatus. These experiments were more or less preliminary, and during their conduct the animal was not submitted to any labour.

Subsequently, Pettenkofer and Voit made experiments in which they determined both the nitrogen in the urine, and the carbonic acid evolved, not only in rest but in work; sometimes fasting, and sometimes with food. Their results were published in 1866, in the *Zeitschrift für Biologie*. The following table gives average results for twenty-four hours, in experiments made with a man, with the aid of Pettenkofer's respiration apparatus:—

TABLE XIII.

	Nitrogen in Urine	Carbonic acid exhaled
IN HUNGER.		
	grams	grams
In rest	12·39	716
In work	12·26	1,187
WITH MODERATE DIET.		
In rest	17·01	928
In work	17·33	1,209

[1] *Untersuchungen über den Einfluss des Kochsalzes, Kaffees und der Muskelbewegungen auf den Stoffwechsel*, 1860.

[2] *Ann. Chem. Pharm.*, II. Supplement-Band, I. Heft, p. 52.

Thus, not only was there no increased transformation of nitrogenous substance by the exercise of force, but there was a very greatly increased exhalation of carbonic acid. It is evident, therefore, that in the exercise of force, the exigency of the system is specially characterised by an increased demand in the food for, so to speak, respiratory material. The results of Pettenkofer and Voit are indeed of great importance; but in Germany they are even looked upon as being the first to establish the correct view on the subject.

Abundant further confirmation of the now generally accepted view is available, and it will be of interest to give some illustrations.

In 1866 results were published [1] as to the amount of nitrogen excreted before, during, and after, ascending the Faulhorn, by Professors Fick and Wislicenus, in August 1865. The experimenters took an ordinary meal at midday on the 29th, but then only starch, fat, and sugar, until after the ascent, which commenced early the next morning. The following is a summary of the results so far as they relate to the point under consideration:—

TABLE XIV.

	Urea	Nitrogen in urea	Total nitrogen	Nitrogen excreted per hour (average)
FICK.				
	grams	grams	grams	grams
Night before ascent . .	12·4820	5·8249	6·9153	0·63
During ascent. . . .	7·0330	3·2681	3·3130	0·41
After ascent	5·1718	2·4151	2·4293	0·40
Night after ascent . . .	—	—	4·8167	0·45
WISLICENUS.				
	grams	grams	grams	grams
Night before ascent . .	11·7614	5·4887	6·6841	0·61
During ascent. . . .	6·6978	3·1254	3·1336	0·39
After ascent	5·1020	2·3809	2·4165	0·40
Night after ascent . . .	—	—	5·3462	0·51

The record of the actual quantities is sufficient to show that much less nitrogen was excreted by both experimenters during, and after, than before the ascent. But the calculated amounts of nitrogen excreted per hour during each of the periods, as given in the last column of the table, bring the main results more clearly to view. It is seen that, on the average, only

[1] *Phil. Mag.*, 1866, 4th Series, vol. xxxi. pp. 485–503.

about two-thirds as much nitrogen was excreted per hour during and after the ascent, as prior to it, when there would be more or less residue in the system from the last albuminous meal.

The above results of Fick and Wislicenus were brought forward by Professor Frankland, in a lecture which he gave at the Royal Institution in 1866—*On the Source of Muscular Power.* He subsequently himself made numerous calorimetrical determinations of the energy evolved by the combustion of muscle, urea, and various foods, or constituents of foods, the results of which were published in a paper—*On the Origin of Muscular Power.*[1] Stated in a few words, his main conclusion was, that the transformation of muscular tissue alone cannot account for more than a small fraction of the muscular power developed by animals.

Dr. Oskar Kellner, who was one of Professor Emil von Wolff's associates in numerous investigations with animals at Hohenheim, made experiments there with a horse[2] from June 15 to August 10, 1878. The daily food of the animal consisted of 5 kilog. meadow-hay, 6 kilog. oats, and 1·5 kilog. wheat-straw-chaff. The horse was made to go different distances, and to draw different weights, the draught being measured by a horse-dynamometer.

The following is a summary of some of the conditions and results of the experiments:—

TABLE XV.

Experiments	Number of days	Live-weight	Per day		
			Work done, kilogram-metres	Urine voided	Nitrogen in urine
		kilog.	kg.-m.	c.c.	grams
1	6	534·1	475,000	6,730	99·0
2	10	529·5	950,000	6,473	109·3
3	14	522·5	1,425,000	8,106	116·8
4	12	508·8	950,000	8,686	110·2
5	14	518·0	475,000	9,548	98·3

In reference to these results, which certainly do show an increased excretion of nitrogen with increased work during the second, third, and fourth periods, as compared with the first and fifth, Kellner considers that they are inconsistent with the conclusions of Pettenkofer and Voit, and others, which connect muscular action more exclusively with the oxidation of non-nitrogenous matters, and that those views require to be modified.

[1] *Phil. Mag.*, 1866, 4th Series, vol. xxxii. pp. 182–199.
[2] *Landwirthschaftliche Jahrbücher*, vol. viii. part v. 1879, pp. 701–712.

At the same time, admitting that the transformation of organic substance is to be considered the source of muscular power, he considers that, in the first line comes the oxidation of non-nitrogenous matters, carbohydrates and fat; in the second, the transformation of circulation-albumin; and lastly, that of the organised albumin, which is only attacked if other matters are not available in sufficient quantity. Further, he considers it is evident that the increased albumin transformation was not sufficient to cover the requirements of the increased work, and that this increased transformation, and the loss of body-weight, show the insufficiency of the food, and of the available fat of the body.

The table, in fact, does show that, with increased work done, there was decline in body-weight; and, assuming with Kellner, that there was a deficiency of food and of body fat, it seems probable that the increased elimination of nitrogen in the urine is the necessary coincident of real dilapidation of the system. It is obvious that, so far as this is the case, the results are not discordant with our own early view on the subject, since fully established by others. These results of Kellner's are, indeed, a confirmation of the view we put forward in 1852, that "A somewhat concentrated supply of nitrogen does, however, in some cases, seem to be required when the system is overtaxed; as for instance when, day by day, more labour is demanded of the animal body than it is competent without deterioration to keep up."

In 1885 Grandeau and Leclerc published the results of an experiment with a horse[1] of which the following is a summary:—

		Nitrogen in urine for 100 in food
Rest		62·4 per cent.
Walking		67·7 „
Trotting		64·9 „
Drawing	Walking	60·9 „
	Trotting	59·2 „

The results show, over the first three experiments, some, but not great, variation in the amount of nitrogen eliminated with exercise; but the amounts are less in the fourth and fifth experiments, and almost identical with walking and trotting. Upon the whole, there is no evidence of direct connexion between the amount of exercise of force and that of nitrogen eliminated in the urine.

The next results give very definite evidence as to the connexion between the amount of carbonic acid exhaled, and that of the force exercised. The experiments were made with

[1] *Annales de la Science Agronomique*, 1885, 2me année, tome i. p. 326.

a horse, by Zuntz and Lehmann, in 1887 and 1888,[1] and the average results were as follows :—

Carbonic acid exhaled per hour (average).

	With Mask	With Tracheal Canula
Rest . . .	3·327 cubic feet.	2·861 cubic feet.
Work . . .	19·643 „ „	17·291 „ „
After work . .	4·662 „ „	3·899 „ „

Thus, then, there were about six times as much carbonic acid exhaled per hour during work as in rest; and when the work had ceased, there was very great reduction in the amount of carbonic acid given off.

The following results by Professor F. Smith, of Aldershot, were published by him in the *Journal of Physiology*,[2] in 1890 :—

TABLE XVI.

	Carbonic acid (CO_2) expired per hour		
	Pony (work, trotting)	Horse (work, galloping)	Horse (work, galloping)
	cubic feet	cubic feet	cubic feet
Rest	0·7648	—	—
Work	2·3954	20·6265	12·4353
After work	0·4631	1·3133	1·1693

As in the experiments of Zuntz and Lehmann, quoted above, the great increase in the amount of carbonic acid exhaled during work, and the great reduction in the amount after the cessation of the work, are here again clearly illustrated.

The next table summarises numerous results, by Professor F. Smith, with horses at different paces (*loc. cit.*, p. 77) :—

TABLE XVII.

	Carbonic acid (CO_2) expired per hour	
	Series A	Series B
	cubic feet	cubic feet
Rest	1·0282	1·2346
Walking	1·0972	1·0586
Trotting	2·9482	4·8309
Cantering	4·9159	5·0080
Galloping	14·9725	—

These strictly gradationary results, with one slight exception, illustrate more clearly still the greater exhalation of carbonic acid the greater the exercise of force.

[1] *Landw. Jahrbücher* vol. xviii. 1889 ,p. 1.

[2] Vol. xi. No. 1.

Turning from the foregoing evidence of direct experiment, indicating the characteristic food requirements for the exercise of force, it will be of interest to give a few examples of the rations adopted as the joint result of direct experiment and large experience.

On p. 94 the results of some experiments by Grandeau and Leclerc with a horse were given, showing no direct connexion between the amount of force exercised and that of nitrogen eliminated in the urine. Their experiments were made at the establishment of the *Petites Voitures* Company in Paris; and the following table gives the standard daily ration of the horses at the time, the experimentally determined maintenance ration, and that finally adopted for work:—

TABLE XVIII.

Ration	Beans	Oats	Maize	Maize cake	Hay	Straw	Total food	Total dry substance
	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.
Previous . . .	1·54	7·23	5·34	1·06	3·84	2·09	21·10	18·14
Maintenance, No. 1.	0·98	4·34	3·20	0·63	2·30	1·24	12·64	10·87
Maintenance, No. 2.	0·84	3·91	2·88	0·57	2·07	1·12	11·39	9·79
For work . .	1·39	6·51	4·81	0·95	3·46	1·87	18·99	16·33

It seems that the system of the establishment was to work the horses on alternate days; and to give less hay, straw, and maize, but more oats and beans, though less total food, on the days of work. The figures in the top line, representing the "Previous" ration, are, in each case, the means of the two days' ration. The "Maintenance Ration, No. 1," was fixed at three-fifths of the "Previous" ration; but, as the animals gained in weight, the "Maintenance Ration, No. 2," which was one-tenth less than No. 1, was subsequently adopted. Even then the horses rather gained in weight. Finally, as it was considered that the standard or "Previous" ration was too high, the ration for work, as given in the bottom line of the table, which is one-and-a-half time as much as the "Maintenance Ration, No. 1," and about one-tenth less than the "Previous" ration, was adopted. It is, however, said that under the new *régime* the horses were somewhat underfed, but whether the reduced ration is still maintained we are not aware. It will be observed that the proportion of the highly nitrogenous leguminous corn (beans), was very small compared with that of the gramineous grains. Still, it will be seen presently that the proportion was very considerably higher than in the case of the omnibus horses of Paris.

The following table gives the average daily ration of the horses of the *General Omnibus Company* of Paris for each of the six years—1879, 1880, 1884, 1885, 1886, and 1887. The average number of horses was about 13,000, and their average weight was from 1,200 to 1,240 lb., whilst, so far as the evidence goes, those of the *Petites Voitures* Company weighed little more than two-thirds as much; and certainly the former are much heavier than, as a rule, are the omnibus or tramway horses of our own country. The figures are calculated from the results given in the annual reports of M. E. Lavalard,[1] the general secretary of the company, the quantities being converted from kilograms into their equivalent in English pounds:—

TABLE XIX.

Year	Beans	Oats	Maize	Hay	Straw	Bran &c.	Total food	Total dry substance
	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.
1879	1·36	10·04	6·85	9·14	10·45	—	37·84	32·17
1880	1·41	8·84	8·25	7·80	11·10	—	37·40	31·83
1884	1·44	8·67	8·53	8·44	8·71	0·91	36·70	31·29
1885	0·89	6·21	11·30	8·50	8·36	0·84	36·10	30·84
1886	0·10	5·51	12·96	8·64	7·32	0·54	35·07	30·03
1887	0·01	8·08	10·77	8·65	8·21	—	35·72	30·52

It will be seen that the actual amount of dry substance supplied per head per day is nearly twice as much as in the case of the *Petites Voitures* horses; that is, much more in proportion to a given live-weight. It will be further seen that the proportion of beans to cereal grains is much less than in the case of the *Petites Voitures* horses, and was reduced to a very small quantity in the later years. In fact, the corn given consisted almost exclusively of oats and maize, that of the oats being reduced, but that of the maize in a greater degree increased, in the later years, coincidently with the reduction in the amount of beans. On the occasion of a visit of one of us to M. Lavalard in 1887, it was suggested to him that the supply of the highly nitrogenous leguminous seeds might be mainly, if not exclusively, reserved for old or overworked horses; and he subsequently informed us that he had found their use in such cases advantageous.

In his annual report for 1886, published in 1887, M. Lavalard gives, on the authority of Dr. Fleming, Principal Veterinary Surgeon of the Army, a list of the average daily rations of horses of tramway companies in the United Kingdom, which are quoted in Table XX. (p. 98) from Dr. Fleming's book.[2]

[1] *Rapports sur les opérations du service de la Cavalerie et des Fourrages.*
[2] *The Practical Horse-Keeper*, by G. Fleming, LL.D., p. 88.

We have also calculated the quantity of dry substance in the total food according to the supposed average composition of each.

There can be little doubt that the average weight of tramway horses in the United Kingdom is much less than that of the omnibus horses of Paris, and it will be seen that the quantity of total food, or total dry matter of food, given per head per day, is also considerably less; though it is much greater than in the case of the smaller *Petites Voitures* horses of Paris.

TABLE XX.

Company	Beans or peas	Oats	Maize	Hay	Straw	Bran	Total food	Total dry substance
	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.
North Metropolitan	2	3	13	7	3	—	28	24·09
London . . .	3	3	7	12	1	—	26	22·20
London Street .	1	3	12	11	—	1	28	24·09
South London .	1	7	7	11	3	—	29	24·76
Birmingham . .	4	10	6	12		—	32	27·30
Liverpool . .	4	—	12	14	—	1	31	26·58
Manchester . .	15			15	—	—	30	25·55
Glasgow . . .	—	6	11	8½	1	0½	27	23·24
Edinburgh . .	4	8	4	14	—[1]	—	32	(25·56)
Dublin . . .	—	3	14	12	—	0½	29½	25·41

[1] Also 2 lb. of "Marshlam"—(Mashlun—Mixed corn?).

The details show that, at any rate at that date, the tramway horses in the United Kingdom received much more of the highly nitrogenous leguminous corn, beans or peas, than the Paris horses; and, according to the figures, this was especially the case in Birmingham, Liverpool, and Edinburgh. Oats and maize nevertheless contributed most of the corn; the maize generally predominating, whilst at the present time it will doubtless do so in a greater degree.

Reviewing the whole of the results which have been adduced illustrating the characteristic food requirements for the exercise of force, it may in the first place be observed that the evidence is cumulative and decisive that, with normal feeding, and with only moderate exercise, there is practically no increased demand for the nitrogenous constituents of food; whilst there is, on the other hand, an increased demand for the more specially respiratory constituents, largely in proportion to the amount of force exercised. If, however, the labour is abnormally heavy, that is, if it be pushed to the point of dilapidation, as indicated by loss of weight, there will, in that case, be an increased elimination of nitrogen in the urine, resulting from the degradation of nitrogenous substance,

and accordingly an increased demand for the nitrogenous constituents of food.

Lastly, it is of interest to observe, that where the subject has been the most carefully investigated, the rations adopted for horses include scarcely any of the more highly nitrogenous foods, such as leguminous seeds; but, in addition to hay and straw-chaff, consist almost exclusively of the comparatively low-in-nitrogen cereal grains, and would, therefore, be characterised by containing a comparatively large amount of digestible non-nitrogenous constituents in proportion to the digestible nitrogenous substance of the food. It has, however, been found that in the case of old or overworked animals, it is advantageous to supply a somewhat larger amount of the highly nitrogenous leguminous seeds. In fact, as we put it in 1852—"a somewhat concentrated supply of nitrogen does, however, in some cases, seem to be required when the system is overtaxed; as for instance, when day by day, more labour is demanded of the animal body than it is competent without deterioration to keep up."

Summary on the Feeding of Animals.

In introducing the subject of the feeding of the animals of the farm, attention was first called to the amount of the constituents of the crops grown in an ordinary four-course rotation, which would, if the grain only were at once sold, be retained upon the farm for further use—in fact, for the production of meat, milk, and manure, and for the exercise of force. There will, as a rule, be a greater or less amount of grass in admixture with the arable land of the farm; and, according to its amount and other circumstances, there will, of course, be more or less stock-food available in addition to that produced on the arable land. So far as manure is concerned, in some cases the grass-land, and in others the arable, will be the gainer by the admixture of the two, accordingly as the one or the other receives back more or less than the amount derived from the consumption of its own produce. Then, again, the influence of the growing modern practice of selling more than the grain, and of importing cattle food and manure from external sources, has to be taken into account. Nevertheless, the illustration derived from a consideration of the proportion of the constituents of the crops grown under a particular system of rotation, which will probably be available for feeding purposes, is not without interest and utility.

The facts and arguments which have been adduced may be very briefly summarised as follows. It has been shown, that the amount of food consumed, both for a given live-weight of animal within a given time, and for the production of a given

amount of increase, is, as our current food-stuffs go, measur
more by the amounts they contain of digestible and avail
non-nitrogenous constituents, than by the amounts of
digestible and available nitrogenous constituents they supply

That this should be the case, so far as the consumption
given live-weight within a given time is concerned, seems c
sistent enough when the prominence of the respiratory funct
in the maintenance of the body, and the large requirement
non-nitrogenous constituents of food to meet the expenditure
respiration, are borne in mind. But, at first sight, it seems l
intelligible that the quantities consumed to produce a giv
amount of increase in live-weight, should also be much mo
dependent on the supplies of the non-nitrogenous, than on tho
of the nitrogenous constituents of food.

It has been shown, however, that store animals may contai
as much, or even more, of the non-nitrogenous substance — fat, tha
of nitrogenous substance; whilst the bodies of fattened animal
may contain two, three, four, or more times as much dry fat as
dry nitrogenous matter. Obviously, therefore, the proportion of
fat to nitrogenous substance in the increase in live-weight of the
fattening animal, must be much higher than in the entire bodies
of the animals.

Then, it has been further shown, that the non-nitrogenous substance of the increase—the fat, is at any rate in great part, if not entirely, derived from the non-nitrogenous constituents of the food.

Of the *nitrogenous* compounds of food, on the other hand, only a small proportion of the whole consumed is finally stored up in the increase of the animal. In other words, a very large amount of nitrogen passes through the body beyond that which is finally retained in the increase, and so remains for manure.

It is, therefore, only what should be expected, that the amount of food consumed to produce a given amount of increase in live-weight, as well as that required for the sustenance of a given live-weight for a given time, should, provided the food be not abnormally deficient in nitrogenous substance, be characteristically dependent on its supplies of digestible and available non-nitrogenous constituents.

Again, it has been shown that, in the exercise of force, there is a greatly increased expenditure of the non-nitrogenous constituents of food, but little, if any, of the nitrogenous.

Thus, then, for maintenance, for increase, and for the exercise of force, the exigencies of the system are characterised more by the demand for the digestible non-nitrogenous or more specially respiratory and fat-forming constituents, than by that for the nitrogenous or more specially flesh-forming ones.

In our paper—*On the Composition of Oxen, Sheep, and Pigs, and of their Increase whilst Fattening*—published in this Journal in 1860, we concluded that—if fattening oxen were liberally fed upon good food, composed of a moderate proportion of cake or corn, some hay or straw chaff, with roots or other succulent food; if sheep were fattened under somewhat similar conditions, but with a less proportion of hay or straw; and if pigs were liberally fed chiefly on cereal grain—the increase would, with as much as 5 or 6 parts of total non-nitrogenous to 1 of nitrogenous compounds in the dry substance of such fattening food, probably be very fat. Further, that in the earlier stages of growth and feeding, a lower proportion of total non-nitrogenous constituents, that is, a higher proportion of the nitrogenous compounds, is desirable; indeed, that it is frequently the most profitable, having regard both to the rapidity of fattening, and to the value of the manure, for the farmer to employ, even up to the end of the feeding process, a somewhat higher proportion of nitrogenous constituents in his stock-foods, than is necessary to yield the maximum proportion of increase in live-weight for a given amount of dry substance of food consumed. But that, when the mixed fattening food contains less than about 5 parts of non-nitrogenous to 1 of nitrogenous compounds, the proportion of increase in live-weight for a given amount of dry substance of the food, will not increase with the increased proportion of nitrogenous compounds consumed; whilst, so far as these are in excess, the proportion of carcass in the live-weight will probably be somewhat less, and the carcasses themselves will be somewhat more bony and fleshy, and less fat.

We at the same time pointed out, however, that the comparative values of food-stuffs, *even as such*, could not be unconditionally determined by the percentage of the total nitrogenous and the total non-nitrogenous constituents; that it was necessary—to examine more closely into the nature and condition of the proximate compounds of food-stuffs; to distinguish those which are digestible and assimilable from those which are not so; to determine the relative values of the comparable or mutually replaceable portions; and, finally, to fix our standards of comparative value with more of reference to direct experimental evidence on the point, and to existing knowledge of the composition of the animal bodies, than had hitherto been usual or even possible.

Since then, an immense amount of labour has been expended in the determination of the digestibility of the individual constituents of various food-stuffs; and the results so far obtained form a valuable contribution to our information on the subject. There is, however, wide variation in the composition of different samples of nominally the same description of food. Then, the

determinations of the amounts of the various constituents remaining undigested have generally been made with animals fed on limited supplies of food, for maintenance only; and the experiments have frequently been made with the individual foods given separately. Great care and reservation are, therefore, necessary in the application of the results to actual practice. Thus, in the liberal feeding of animals for the production of increase, it is generally economical to give, within limits, an excess of food, if a maximum result is to be obtained for a given live-weight of animal within a given time; and, in the case of animals liberally fed for the exercise of force, there will also generally be an excess of food given. It is obvious that, under the conditions of actual practice here assumed, greater proportions of the various constituents consumed will remain undigested than would be indicated by the figures representing indigestibility obtained under the usual conditions of experimenting on the point above referred to. Then there is the important consideration, that conclusive evidence is still wanting as to the exact *rôle* in the system of some prominent constituents of food-stuffs. For example, there is yet much uncertainty in regard to the position of the various amides, which enter so largely into the composition of feeding roots and hays—in fact of all succulent and unripened products. Indeed, in the calculation of "nutritive ratios," the amides have sometimes been classed with the albuminoids, and sometimes in large proportion with the non-nitrogenous constituents. We have, from time to time, had the results of our numerous feeding experiments, with both sheep and pigs, calculated according to the published tables of digestibility. But the so-calculated "ratios" varied so considerably for different rations within the range of good practice, that it would be misleading to attempt to give anything like a summary of the results, and general conclusions therefrom, without full discussion.

In conclusion, as our current fattening food-stuffs go, assuming, of course, that they are not abnormally low in the nitrogenous constituents, they are, *as foods*, more valuable in proportion to their richness in digestible and available non-nitrogenous than to that of their nitrogenous constituents. As, however, the manure of the animals of the farm is valuable largely in proportion to the nitrogen it contains, there is, so far, an advantage in giving a food somewhat rich in nitrogen, provided it is in other respects a good one, and, weight for weight, not much more costly.

JOHN BENNET LAWES.
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LIVE-WEIGHT PER WEEK.

14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	EXPERIMENTS
6·0	3·9	5·7	3·7	3·1	3·1	3·7	3·7	3·1	3·8	3·4	3·5	4·5	4·1	4·1	4·7	3·9	(NON-NIT. SUB / TO NIT. SUB

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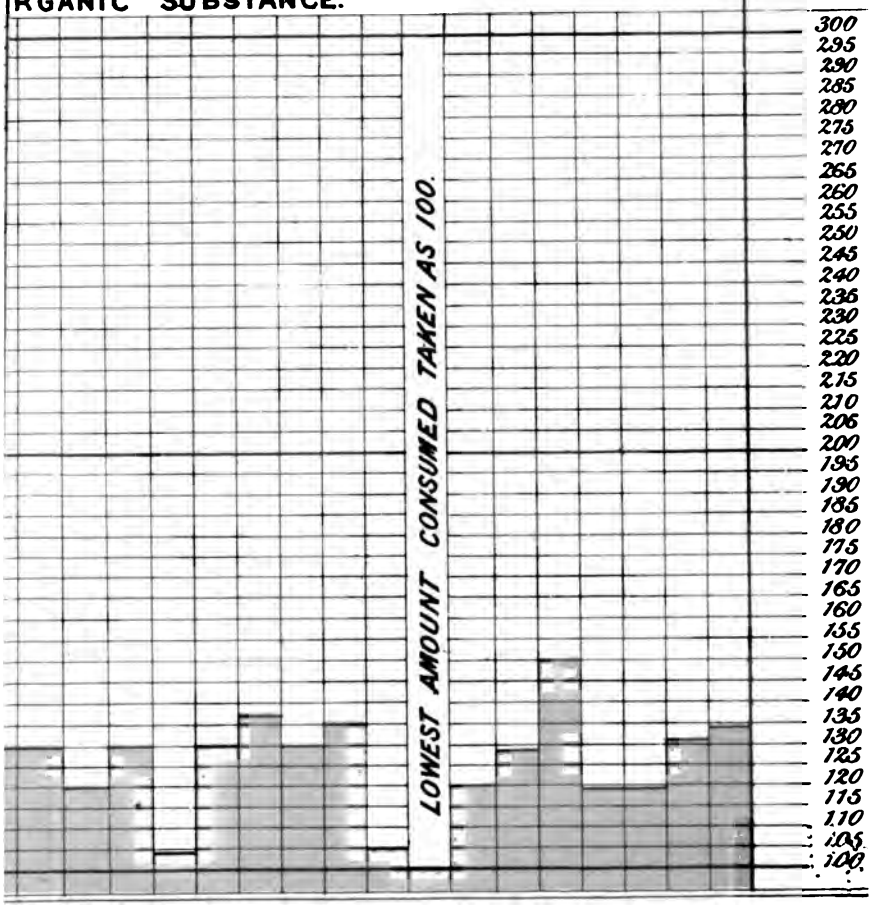

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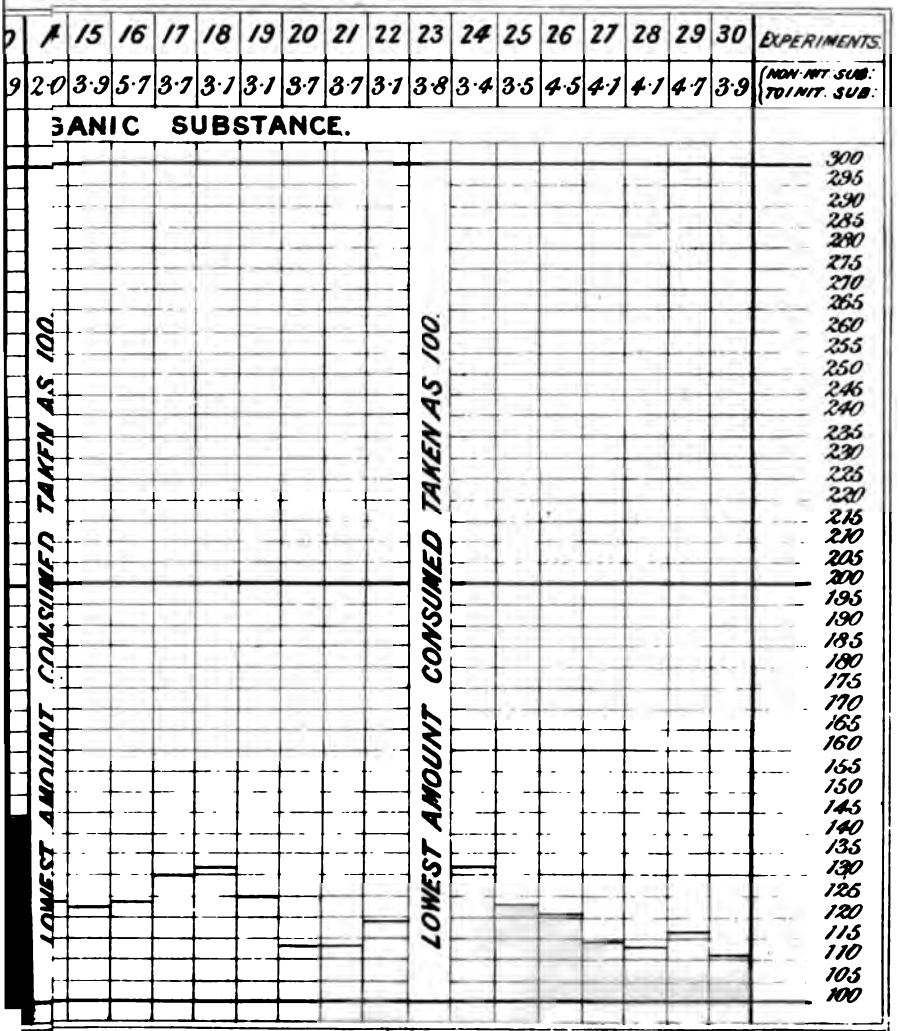

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